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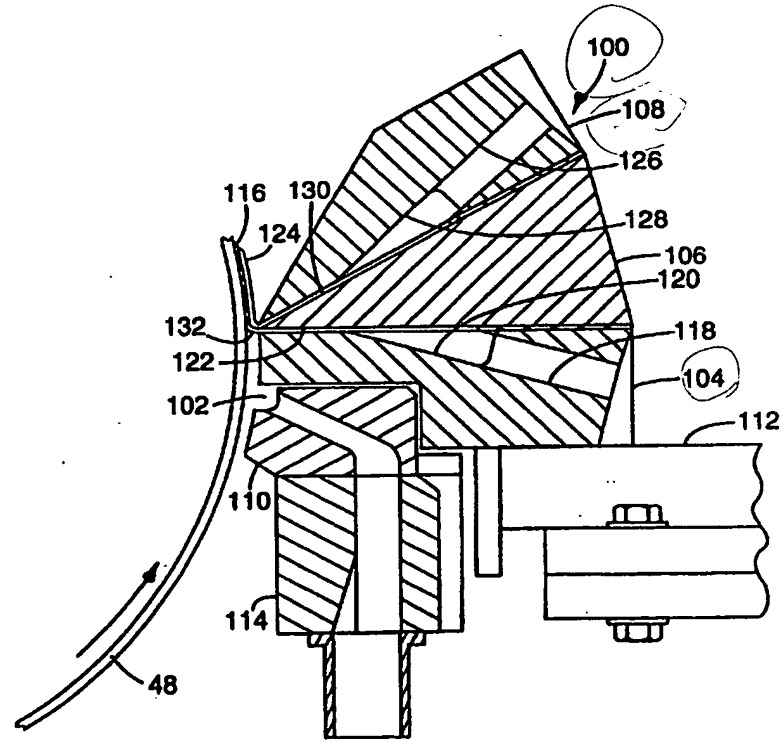
(57) Abstract

A die coating method and apparatus includes a die (100, 150, 220) having an upstream bar (104, 154, 226) with an upstream lip, a central bar, a downstream bar (108, 158, 232) with a downstream lip, and a vacuum bar (110, 160, 224). The upstream lip is formed as a land and the first manifold bar is formed as a sharp edge. The shape of the land conforms to the shape of the surface being coated. Changing at least one of the slot heights H, the overbites O, and the convergence C can improve coating performance. The die can have a slide surface (236, 244) and the coating fluid can exit the die from a passageway and slides along the slide surface to form a continuous coating bead between the manifold bar sharp edge, the upstream die lip, and the surface being coated. The die can include several passageways for coating multiple layers.



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MULTIPLE LAYER AND SLIDE DIE COATING METHOD AND APPARATUS

TECHNICAL FIELD

The present invention relates to coating methods. More particularly, the present invention relates to coating methods using a die.

BACKGROUND OF THE INVENTION

U.S. Patent No. 2,681,294 discloses a vacuum method for stabilizing the coating bead for direct extrusion and slide types of metered coating systems. Such stabilization enhances the coating capability of these systems. However, these coating systems lack sufficient overall capability to provide the thin wet layers, even at very low liquid viscosities, required for some coated products.

U.S. Patent No. 2,761,791 teaches using various forms of extrusion and slide coaters to bead-coat multiple liquids simultaneously in a distinct layer relationship onto a moving web. However, these coating systems lack sufficient overall performance to maintain the desired multiple wet layer thickness at the needed web speeds and coating gaps, for some coated products. U.S. Patent No. 5,256,357 discloses a multiple layer coating die with an underbite in one of the slot edges. Underbite in one of the two edges improves the coating situation in some cases.

U.S. Patent No. 4,445,458 discloses an extrusion type bead-coating die with a beveled draw-down surface to impose a boundary force on the downstream side of the coating bead and to reduce the amount of vacuum necessary to maintain the bead. Reduction of the vacuum minimizes chatter defects and coating streaks. To improve coating quality, the obtuse angle of the beveled surface with respect to

the slot axis, and the position along the slot axis of the bevel toward the moving web (overhang) and away from the moving web (underhang) must be optimized. The optimization results in the high quality needed for coating photosensitive emulsions. However, the thin-layer performance capability needed for some coated products is lacking.

U.S. Patent No. 3,413,143 discloses a two slot die with excess coating liquid pumped into the coating bead area through the upstream slot. Approximately half of the entering liquid is pumped out of the bead area through the downstream slot and the remainder is applied to the moving web. The excess liquid in the bead has a stabilizing effect, which improves performance without using a vacuum chamber. However, this apparatus does not provide the performance needed for some coated products, with a maximum stated gap-to-wet-thickness ratio of only 3.

U.S. Patent No. 4,443,504 discloses a slide coating apparatus in which the angle between the slide surface and a horizontal datum plane ranges from 35° to 50° and the takeoff angle defined between a tangent to the coating roll and the slide surface ranges from 85° to 100°. Operation within these ranges provides a compromise between performance from high fluid momentum down the slide and coating uniformity from high liquid levelling force against the slide surface. However, even with a vacuum chamber, this system does not provide the performance needed for some coated products.

European Patent Application No. EP 552653 describes covering a slide coating die surface adjacent to and below the coating bead with a low energy fluorinated polyethylene surface. The covering starts 0.05-5.00 mm below the coating lip tip and

extends away from the coating bead. The low-surface-energy covering is separated from the coating lip tip by a bare metal strip. This locates the bead static contact line. The low energy covering eliminates coating streaks and facilitates die cleanup. No mention is made of using this with an extrusion coating die.

Figure 1 shows a known coating die 10 with a vacuum chamber 12 as part of a metered coating system. A coating liquid 14 is precisely supplied by a pump 16 to the die 10 for application to a moving web 18, supported by a backup roller 20. Coating liquid is supplied through a channel 22 to a manifold 24 for distribution through a slot 26 in the die and coating onto the moving web 18. As shown in Figure 2, the coating liquid passes through the slot 26 and forms a continuous coating bead 28 between the upstream die lip 30 and the downstream die lip 32, and the web 18. Dimensions f_1 and f_2, the width of the lips 30, 32 commonly range from 0.25 to 0.76 mm. The vacuum chamber 12 applies a vacuum upstream of the bead to stabilize the bead. While this configuration works adequately in many situations, there is a need for a die coating method which improves the performance of known methods.

SUMMARY OF THE INVENTION

The present invention is a die coating apparatus for coating multiple layers of fluid coating onto a surface. The apparatus includes a die having an upstream bar with an upstream lip, a wedge bar with a wedge edge, and a downstream bar with a downstream lip. The upstream lip is formed as a land, the wedge edge is formed as a sharp edge, and the downstream lip is formed as a sharp edge. A first passageway runs through the die between the upstream bar and the wedge

bar and a second passageway running through the die between the wedge bar and the downstream bar. The first passageway has a first slot defined by the upstream lip and the wedge edge and the second passageway has a second slot defined by the wedge edge and the downstream lip. A first coating fluid exits the die from the first slot to form a continuous coating bead between the upstream die lip, the wedge edge, and the surface being coated for application onto the surface being coated. A second coating fluid exits the die from the second slot to form a continuous coating bead between the wedge edge, the downstream die lip, and the surface being coated for application onto the first coating fluid. The bead does not significantly move into the space between the land and the surface to be coated even as vacuum is increased.

The shape of the land conforms to the shape of the surface being coated. Where the surface is curved, the land is curved. The die also can include applying a vacuum upstream of the bead to stabilize the bead. The vacuum can be applied using a vacuum chamber having a vacuum bar with a land. The shape of the vacuum land also conforms to the shape of the surface being coated. The land and the vacuum land can have the same radius of curvature and can have the same or different convergences with respect to the surface to be coated.

Changing at least one of the slot height, the overbite, and the convergence can improve coating performance. The slot height, the overbite, and the convergence are selected in combination with each other and the length of the land, the edge angle of the downstream bar, the die attack angle between the downstream bar surface of the coating slot and a tangent plane through a line on the surface to be

coated parallel to, and directly opposite, the sharp edge, and the coating gap distance between the sharp edge and the surface to be coated are selected in combination with each other.

In an alternative embodiment, the die includes an upstream bar with an upstream lip, a separator, and a downstream bar with a downstream lip. The upstream lip is formed as a land and the downstream lip is formed as a sharp edge. A first passageway runs through the die between the upstream bar and the separator and a second passageway runs through the die between the separator and the downstream bar. The first and second passageways combine to form a single slot defined by the upstream lip and the downstream lip. The two coating fluids are brought together inside the die slot and flow through the slot as separate, laminar layers which form a coating bead and transfer to the surface to be coated.

The method of die coating according to this invention includes passing a first coating fluid through a first slot; passing a second coating fluid through a second slot; forming a continuous coating bead with the first coating fluid between the upstream die lip, the wedge edge, and the surface being coated for application onto the surface being coated; and forming a continuous coating bead with the second coating fluid between the wedge edge, the downstream die lip, and the surface being coated for application onto the first coating fluid. The bead does not significantly move into the space between the land and the surface to be coated even as vacuum is increased.

The method can also include selecting the length of the land, the edge angle of the downstream bar, the die attack angle between the downstream bar surface of the coating slot and a tangent plane

through a line on the surface to be coated parallel to, and directly opposite, the downstream lip sharp edge, and the coating gap distance between the downstream lip sharp edge and the surface to be coated in combination with each other; and selecting the slot heights, the overbites, and the convergence in combination with each other. The method can also include the step of applying a vacuum upstream of the bead to stabilize the bead.

An alternative method includes passing a first coating fluid through a first passageway; passing a second coating fluid through a second passageway; bringing together the first and second coating fluids inside a die slot; flowing the first and second coating fluids through the slot as separate, laminar layers which form a coating bead; and transferring the bead to the surface to be coated.

The present invention is a die coating apparatus for coating fluid coating onto a surface. The apparatus includes a die having an upstream bar with an upstream lip, a manifold bar, a downstream bar with a downstream lip, a vacuum bar, and a slide surface. The upstream lip is formed as a land and the first manifold bar is formed as a sharp edge. A first passageway runs through the die between the manifold bar and the downstream bar. The coating fluid exits the die from the passageway and slides along the slide surface to form a continuous coating bead between the manifold bar sharp edge, the upstream die lip, and the surface being coated. The bead does not significantly move into the space between the land and the surface to be coated even as vacuum is increased. The shape of the land conforms to the shape of the surface being coated.

The invention also is a multiple layer die coating apparatus for coating multiple layers of fluid

coatings onto a surface. This apparatus includes a die having an upstream bar with an upstream lip, a first manifold bar, a second manifold bar, a downstream bar with a downstream lip, a vacuum bar, and a slide surface. The upstream lip is formed as a land and the first manifold bar is formed as a sharp edge. A first passageway runs through the die between the first manifold bar and the second manifold bar. The first coating fluid exits the die from the first passageway and slides along the slide surface to form a continuous coating bead between the manifold bar sharp edge, the upstream die lip, and the surface being coated, for application onto the surface to be coated. A second passageway runs through the die between the second manifold bar and the downstream bar. The second coating fluid exits the die from the second passageway and slides along the slide surface to form a continuous coating bead between the manifold bar sharp edge, the upstream die lip, and the surface being coated, for application onto the first coating fluid.

The method of die coating according to this invention includes passing coating fluid through a passageway defined by a manifold bar having a sharp edge and a downstream bar with a downstream lip; and sliding the coating fluid exiting from the passageway along a slide surface to form a continuous coating bead between the manifold bar sharp edge, an upstream die lip formed as a land, and the surface being coated. The bead does not significantly move into the space between the land and the surface to be coated even as vacuum is increased.

The method can also include selecting the length of the land, the edge angle of the first manifold bar and the coating gap distance between the sharp edge and the surface to be coated in combination

with each other; and selecting the overbite and the convergence in combination with each other.

A method of coating multiple layers includes passing a first coating fluid through a first passageway defined by a first manifold bar formed as a sharp edge and a second manifold bar; sliding the first coating fluid which exits from the first passageway along a slide surface; forming a continuous coating bead between the manifold bar sharp edge, an upstream die lip, and the surface being coated, for application of the first coating fluid onto the surface to be coated; passing a second coating fluid through a second passageway defined by the second manifold bar and a downstream bar; sliding the second coating fluid which exits from the second passageway along a slide surface; and forming a continuous coating bead between the manifold bar sharp edge, an upstream die lip, and the surface being coated, for application of the second fluid onto the first coating fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic, cross-sectional view of a known coating die.

Figure 2 is an enlarged cross-sectional view of the slot and lip of the die of Figure 1.

Figure 3 is a cross-sectional view of an extrusion die of the present invention.

Figure 4 is an enlarged cross-sectional view of the slot and lip of the die of Figure 4.

Figure 5 is a cross-sectional view of the slot and lip similar to that of Figure 4.

Figure 6 is a cross-sectional view of an alternative vacuum chamber arrangement.

Figure 7 is a cross-sectional view of another alternative vacuum chamber arrangement.

Figure 8 is a cross-sectional view of an alternative extrusion die of the present invention.

Figures 9a and 9b are enlarged cross-sectional views of the slot, face, and vacuum chamber of the die of Figure 8.

Figures 10a and 10b are schematic views of the die of Figure 8.

Figure 11 shows coating test results which compare the performance of a known extrusion die and an extrusion die of the present invention for a coating liquid of 1.8 centipoise viscosity.

Figure 12 shows comparative test results for a coating liquid of 2.7 centipoise viscosity.

Figure 13 is a collection of data from coating tests.

Figure 14 is a graph of constant G/Tw lines for an extrusion coating die of the present invention for nine different coating liquids.

Figure 15 is a cross-sectional view of a multiple layer extrusion die according to the present invention.

Figure 16 is a cross-sectional view of the face and vacuum chamber of the die of Figure 15.

Figure 17 is a cross-sectional view of another embodiment of a multiple layer extrusion die.

Figure 18 is a cross-sectional view of the face and vacuum chamber of the die of Figure 17.

Figure 19 is a cross-sectional view of a known slide coating die.

Figure 20 is a cross-sectional view of a multiple layer slide coating die of the present invention.

Figure 21 is a cross-sectional view of a multiple layer, combination extrusion and slide coater of the present invention.

Figure 22 is a cross-sectional view of the die according to another embodiment of the present invention.

Figure 23 is a cross-sectional view of a multiple layer version of the die of Figure 22.

Figure 24 is a cross-sectional view of a multiple layer, combination extrusion and slide version of the die of Figure 22.

DETAILED DESCRIPTION

This invention is a die coating method and apparatus where the die includes a sharp edge and a land which are positioned to improve and optimize performance. The land is configured to match the shape of the surface in the immediate area of coating liquid application. The land can be curved to match a web passing around a backup roller or the land can be flat to match a free span of web between rollers.

Figure 3 shows the extrusion die 40 with a vacuum chamber 42 of the present invention. Coating liquid 14 is supplied by a pump 46 to the die 40 for application to a moving web 48, supported by a backup roller 50. Coating liquid is supplied through a channel 52 to a manifold 54 for distribution through a slot 56 and coating onto the moving web 48. As shown in Figure 4, the coating liquid 14 passes through the slot 56 and forms a continuous coating bead 58 among the upstream die lip 60, the downstream die lip 62, and the web 48. The coating liquid can be one of numerous liquids or other fluids. The upstream die lip 60 is part of an upstream bar 64, and the downstream die 62 lip is part of a downstream bar 66. The height of the slot 56 can be controlled by a U-shaped shim which can be made of brass or stainless steel and which can be deckled. The vacuum chamber 42

applies vacuum upstream of the bead to stabilize the coating bead.

As shown in Figure 5, the upstream lip 60 is formed as a curved land 68 and the downstream lip 62 is formed as a sharp edge 70. This configuration improves overall performance over that of known die-type coaters. Improved performance means permitting operating at increased web speeds and increased coating gaps, operating with higher coating liquid viscosities, and creating thinner wet coating layer thicknesses.

The sharp edge 70 should be clean and free of nicks and burrs, and should be straight within 1 micron in 25 cm of length. The edge radius should be no greater than 10 microns. The radius of the curved land 68 should be equal to the radius of the backup roller 50 plus a minimal, and non-critical, 0.13 mm allowance for coating gap and web thickness. Alternatively, the radius of the curved land 68 can exceed that of the backup roller 50 and shims can be used to orient the land with respect to the web 48. A given convergence C achieved by a land with the same radius as the backup roller can be achieved by a land with a larger radius than the backup roller by manipulating the land with the shims.

Figure 5 also shows dimensions of geometric operating parameters for single layer extrusion. The length L_1 of the curved land 68 on the upstream bar 64 can range from 1.6 mm to 25.4 mm. The preferred length L_1 is 12.7 mm. The edge angle A_1 of the downstream bar 66 can range from 20° to 75°, and is preferably 60°. The edge radius of the sharp edge 70 should be from about 2 microns to about 4 microns and preferably less than 10 microns. The die attack angle A_2 between the downstream bar 66 surface of the coating slot 56 and the tangent plane P through a line

on the web 48 surface parallel to, and directly opposite, the sharp edge 70 can range from 60° to 120° and is preferably 90°-95°, such as 93°. The coating gap G_1 is the perpendicular distance between the sharp edge 70 and the web 48. (The coating gap G_1 is measured at the sharp edge but is shown in some Figures spaced from the sharp edge for drawing clarity. Regardless of the location of G_1 in the drawings - and due to the curvature of the web the gap increases as one moves away from the sharp edge - the gap is measured at the sharp edge.)

Slot height H can range from 0.076 mm to 3.175 mm. Overbite O is a positioning of the sharp edge 70 of the downstream bar 66, with respect to the downstream edge 72 of the curved land 68 on the upstream bar 64, in a direction toward the web 48. Overbite also can be viewed as a retraction of the downstream edge 72 of the curved land 68 away from the web 48, with respect to the sharp edge 70, for any given coating gap G_1. Overbite can range from 0 mm to 0.51 mm, and the settings at opposite ends of the die slot should be within 2.5 microns of each other. A precision mounting system for this coating system is required, for example to accomplish precise overbite uniformity. Convergence C is a counterclockwise, as shown in Figure 5, angular positioning of the curved land 68 away from a location parallel to (or concentric with) the web 48, with the downstream edge 72 being the center of rotation. Convergence can range from 0° to 2.29°, and the settings at opposite ends of the die slot should be within 0.023° of each other. The slot height, overbite, and convergence, as well as the fluid properties such as viscosity affect the performance of the die coating apparatus and method.

From an overall performance standpoint, for liquids within the viscosity range of 1,000 centipoise and below, it is preferred that the slot height be 0.18 mm, the overbite be 0.076 mm, and the convergence be 0.57°. Performance levels using other slot heights can be nearly the same. Performance advantages can also be found at viscosities above 1,000 centipoise. Holding convergence at 0.57°, some other optimum slot height and overbite combinations are as follows:

Slot Height	Overbite
0.15 mm	0.071 mm
0.20 mm	0.082 mm
0.31 mm	0.100 mm
0.51 mm	0.130 mm

In the liquid viscosity range noted above, and for any given convergence value, the optimum overbite value appears to be directly proportional to the square root of the slot height value. Similarly, for any given slot height value, the optimum overbite value appears to be inversely proportional to the square root of the convergence value.

As shown in Figure 6, the vacuum chamber 42 can be an integral part of, or clamped to, the upstream bar 64 to allow precise, repeatable vacuum system gas flow. The vacuum chamber 42 is formed using a vacuum bar 74 and can be connected through an optional vacuum restrictor 76 and a vacuum manifold 78 to a vacuum source channel 80. A curved vacuum land 82 can be an integral part of the upstream bar 64, or can be part of the vacuum bar 74, which is secured to the upstream bar 64. The vacuum land 82 has the same radius of curvature as the curved land 68. The curved land 68 and the vacuum land 82 can be finish-ground together so they are "in line" with each other. The

vacuum land 82 and the curved land 68 then have the same convergence C with respect to the web 48.

The vacuum land gap G_2 is the distance between the vacuum land 82 and the web 48 at the lower edge of the vacuum land and is the sum total of the coating gap G_1, the overbite O, and the displacement caused by convergence C of the curved land 68. (Regardless of the location of G_1 in the drawings the gap is the perpendicular distance between the lower edge of the vacuum land and the web.) When the vacuum land gap G_2 is large, an excessive inrush of ambient air to the vacuum chamber 42 occurs. Even though the vacuum source may have sufficient capacity to compensate and maintain the specified vacuum pressure level at the vacuum chamber 42, the inrush of air can degrade coating performance.

In Figure 7, the vacuum land 82 is part of a vacuum bar 74 which is attached to the upstream bar 64. During fabrication, the curved land 68 is finished with the convergence C "ground in." The vacuum bar 74 is then attached and the vacuum land 82 is finish ground, using a different grind center, such that the vacuum land 82 is parallel to the web 48, and the vacuum land gap G_2 is equal to the coating gap G_1 when the desired overbite value is set. The vacuum land length L_2 may range from 6.35 mm to 25.4 mm. The preferred length L_2 is 12.7 mm. This embodiment has greater overall coating performance capability in difficult coating situations than the embodiment of Figure 6, but it is always finish ground for one specific set of operating conditions. So, as coating gap G_1 or overbite O are changed vacuum land gap G_2 may move away from its optimum value.

In Figures 8 and 9 the upstream bar 64 of the die 40 is mounted on an upstream bar positioner 84, and the vacuum bar 74 is mounted on a vacuum bar

positioner 86. The curved land 68 on the upstream bar 64 and the vacuum land 82 on the vacuum bar 74 are not connected directly to each other. The vacuum chamber 42 is connected to its vacuum source through the vacuum bar 74 and the positioner 86. The mounting and positioning for the vacuum bar 74 are separate from those for the upstream bar 64. This improves performance of the die and allows precise, repeatable vacuum system gas flow. The robust configuration of the vacuum bar system also aids in the improved performance as compared with known systems. Also, this configuration for the vacuum bar 74 could improve performance of other known coaters, such as slot, extrusion, and slide coaters. A flexible vacuum seal strip 88 seals between the upstream bar 64 and the vacuum bar 74.

The gap G_2 between the vacuum land 82 and the web 48 is not affected by coating gap G_1, overbite O, or convergence C changes, and may be held at its optimum value continuously, during coating. The vacuum land gap G_2 may be set within the range from 0.076 mm to 0.508 mm. The preferred value for the gap G_2 is 0.15 mm. The preferred angular position for the vacuum land 82 is parallel to the web 48.

During coating, the vacuum level is adjusted to produce the best quality coated layer. A typical vacuum level, when coating a 2 centipoise coating liquid at 6 microns wet layer thickness and 30.5 m/min web speed, is 51 mm H_2O. Decreasing wet layer thickness, increasing viscosity, or increasing web speed could require higher vacuum levels exceeding 150 mm H_2O. Dies of this invention exhibit lower satisfactory minimum vacuum levels and higher satisfactory maximum vacuum levels than known systems, and in some situations can operate with zero vacuum where known systems cannot.

Figures 10a and 10b show some positioning adjustments and the vacuum chamber closure. Overbite adjustment translates the downstream bar 66 with respect to the upstream bar 64 such that the sharp edge 70 moves toward or away from the web 48 with respect to the downstream edge 72 of the curved land 68. Adjusting convergence rotates the upstream bar 64 and the downstream bar 66 together around an axis running through the downstream edge 72, such that the curved land 68 moves from the position shown in Figure 10, away from parallel to the web 48, or back toward parallel. Coating gap adjustment translates the upstream bar 64 and the downstream bar 66 together to change the distance between the sharp edge 70 and the web 48, while the vacuum bar remains stationary on its mount 86, and the vacuum seal strip 88 flexes to prevent air leakage during adjustments. Air leakage at the ends of the die into the vacuum chamber 42 is minimized by end plates 90 attached to the ends of the vacuum bar 74 which overlap the ends of the upstream bar 64. The vacuum bar 74 is 0.10 mm to 0.15 mm longer than the upstream bar 64, so, in a centered condition, the clearance between each end plate 90 and the upstream bar 64 will range from 0.050 mm to 0.075 mm.

One unexpected operating characteristic has been observed during coating. The bead does not move significantly into the space between the curved land 68 and the moving web 48, even as vacuum is increased. This allows using higher vacuum levels than is possible with known extrusion coaters, and provides a correspondingly higher performance level. Even where little or no vacuum is required, the invention exhibits improved performance over known systems. That the bead does not move significantly into the space between the curved land 68 and the web 48 also

means that the effect of "runout" in the backup roller 50 on downstream coating weight does not differ from that for known extrusion coaters.

Figure 11 graphs results of coating tests which compare the performance of a known extrusion die with an extrusion die of this invention. In the tests, the 1.8 centipoise coating liquid containing an organic solvent was applied to a plain polyester film web. The performance criterion was minimum wet layer thickness at four different coating gap levels for each of the two coating systems, over the speed range of 15 to 60 m/min. Curves A, B, C, and D use the known, prior art die and were performed with coating gaps of 0.254 mm, 0.203 mm, 0.152 mm, and 0.127 mm, respectively. Curves E, F, G, and H use a die according to this invention at the same respective coating gaps. The lower wet thickness levels for this invention, compared to the prior art die, are easily visible. Figure 12 shows comparative test results for a similar coating liquid of 2.7 centipoise viscosity, at the same coating gaps. Once again, the performance advantage for this invention is clearly visible.

Figure 13 is a collection of data from coating tests where liquids at seven different viscosities, and containing different organic solvents, were applied to plain polyester film webs. The results compare performance of the prior art extrusion coater (PRIOR) and this invention (NEW). The performance criteria are mixed. Performance advantages for this invention can be found in web speed (Vw), wet layer thickness (Tw), coating gap, vacuum level, or a combination of these.

One measure of coater performance is the ratio of coating gap to wet layer thickness (G/Tw), for a particular coating liquid and web speed. Figure 14 shows a series of constant G/Tw lines and viscosity

values of an extrusion die of this invention, for nine different coating liquids. The liquids were coated on plain polyester film base at a web speed of 30.5 m/min. A few viscosity values appear to be out of order, due to the effect of other coatability factors. Four additional performance lines have been added after calculating the G/Tw values for 30.5 m/min web speed from Figures 11 and 12. From top to bottom, the solid performance lines are the G/Tw for liquids of 2.7 centipoise and 1.8 centipoise coated by a known extrusion die and the G/Tw for liquids of 2.7 centipoise and 1.8 centipoise coated by an extrusion die of this invention. The lines for of this invention represent greater G/Tw values than the lines for of the prior art coating die. In addition, the lines for this invention are close to being lines of constant G/Tw, averaging 18.8 and 16.8, respectively. The lines of the known coater show considerably more G/Tw variation over their length. This invention has a much improved operating characteristic for maintaining a coating bead at low wet thickness values, over known systems.

Figures 15 and 16 show a multiple layer extrusion die 100 with a vacuum chamber 102 of this invention. The die 100 includes an upstream bar 104, a wedge bar 106, and a downstream bar 108. Vacuum pressure for the vacuum chamber 102 is supplied through a vacuum bar 110. The upstream bar 104 is mounted on an upstream bar positioner 112 and the vacuum bar 110 is supported by a vacuum bar positioner 114. A first coating liquid 116 is supplied through a first channel 118 to a first manifold 120 for distribution through a first slot 122 to form a first wet coated layer on the web 48. A second coating liquid 124 is supplied through a second channel 126 to a second manifold 128 for distribution through a

second slot 130 to form a second wet coated layer on the first coated layer. The two liquids are brought together at the coating bead 132.

Alternatively, the second channel 126 could be formed in the wedge bar 106. Additionally, channels (not shown) can be formed transversely through the die 100, such as through the wedge bar 106. The channels can receive cool or warm water or other fluid to cool or heat the die.

In this configuration, two sharp edges, downstream edge 134 and wedge edge 136, can have overbite adjustment. Two flow slots 122, 130, each can have slot height adjustment. It has been found that underbite in one of these two edges can improve the multiple layer coating situation in some cases. For both edges 134, 136 overbite (toward the web 48) and underbite (away from the web 48) are measured with respect to a downstream edge 138 of the curved land 140. The adjustment for the sharp edge 134 on the downstream bar 108, moving along the coating slot 130 can range from 0.51 mm underbite to 0.51 mm overbite. The adjustment for the wedge edge 136 on the wedge bar 106, moving along the coating slot 122 can range be from 0.51 mm underbite to 0.51 mm overbite. Both slot heights H_1, H_2 can range from 0.076 mm to 3.175 mm. With convergence on the curved land 140 set at 0.57°, and both slot heights at 0.254 mm, the preferred overbite values are 0.0 mm for the wedge edge 136 and 0.076 mm overbite for the downstream edge 134 on the downstream bar 108. The gap between the vacuum land 142 on the vacuum bar 110, and the web 48 can range from 0.076 mm to 0.508 mm, but preferably is 0.15 mm. A flexible seal strip 144 seals between the upstream bar 104 and the vacuum bar 110. The principles of this die also can be applied to multiple layer dies for coating three or more layers.

Figures 17 and 18 show an alternative embodiment of a multiple layer extrusion die 150 with a vacuum chamber 152. The die 150 includes an upstream bar 154, a slot shim 156, and a downstream bar 158. Vacuum pressure for the vacuum chamber 152 is supplied through a vacuum bar 160. The upstream bar 154 is mounted on an upstream bar positioner 162 and the vacuum bar 160 is supported by a vacuum bar positioner 164. The first coating liquid 116 is supplied through a first channel 166 to a first manifold 168, while the second coating liquid 124 is supplied through a second channel 170 to a second manifold 172. The two coating liquids are brought together inside the die 150 and flow through the slot 174 as separate, laminar layers. The coating liquids 116, 124 pass through the coating bead 176, and form the two wet coated layers on the web 48. Alternatively, a wedge bar can be used in place of the slot shim 156 to separate the two manifolds 168, 172.

Only one sharp edge 178 on the downstream bar 158 is involved in overbite adjustment with respect to downstream edge 180 of the curved land 182 on the upstream bar 154. Ranges for slot height, overbite, and convergence are the same as those specified for Figure 5. Preferably, the slot height is 0.18 mm, the overbite is 0.076 mm, and the convergence is 0.57°. The gap range between the vacuum land 184 on the vacuum bar 160 and the web 48 is from 0.076 mm to 0.508 mm, and preferably is 0.15 mm. A flexible seal strip 186 prevents leakage between the upstream bar 154 and the vacuum bar 160.

Figure 19 shows a known slide coating die 200 using a vacuum chamber 202 and having a liquid distribution manifold 204, a flow slot 206, and a slide surface 208. Coating liquid is coated onto a web 18 passing around a backup roller 20. A coating

bead edge 210 is a 3.2 mm wide flat face extending across the die. The bead edge 210 is commonly positioned along a backup roller radius line R at an angle A_3, 10° below horizontal, to incline the die slide surface 208 at an angle A_4, 25° below horizontal.

Figure 20 shows a multiple layer slide coating die 220 of the present invention having a conventional face angle using a vacuum chamber 222. The die 220 includes a vacuum bar 224, an upstream bar 226, a first manifold bar 228, a second manifold bar 230, and a downstream bar 232. The coating bead edge 238 is positioned along a backup roller radius line R at an angle A_3, 10° below horizontal, such that the die slide surface 236 is inclined at an angle A_4, 25° below horizontal. Dimensions and positions of interest are the bead edge angle A_1, the overbite O, the convergence C, the coating gap G_1, and the vacuum land gap G_2. There is no flow slot to supply coating liquid directly to the coating bead. The coating liquid flows down the slide surface 236 and over the bead edge 238. This slide coating die shows improved performance over known slide coaters. The bead edge angle A_1 can vary from 50° to 90°. The preferred bead edge angle A_1 is 80°. With convergence C set at 0.57°, the preferred overbite O is 0.076 mm. In operation, the first coating liquid 116 passes through the first slot 240 and down the slide surface 236 to the coating bead where it forms a first layer on the web 48. The second coating liquid 124 passes through a second slot 242 down the slide surface 244 and over the first coating liquid on the slide surface 236 to the coating bead where it forms a second layer on the first layer.

Figure 21 shows a combination extrusion and slide coater 250 of the present invention which can be used with multiple or single layer, combination

extrusion and slide coaters. The coater 250 includes a vacuum bar 224, an upstream bar 226, a first manifold bar 228, a second manifold bar 230, and a downstream bar 232. The bead edge 238 is positioned along a backup roller radius line R at an angle A_3, 10° below horizontal, such that the die slide surface 236 is inclined at an angle A_4, 25° below horizontal. Alternatively, the bead edge 238 can be positioned so that the fluid exiting from the first slot 252 exits perpendicular to the web 48 at the point of application.

Dimensions and positions of interest are the bead edge angle A_1, the first slot 252 height, the overbite O, the convergence C, the coating gap G_1, and the vacuum land gap G_2. The preferred bead edge angle A_1 is 80°. With convergence set at 0.57°, and the first slot 252 height at 0.15 mm, the preferred overbite is 0.076 mm. The first liquid 116 passes through the first slot 252 to the coating bead, where it forms a first coated layer on the web 48. The second liquid 124 passes through the second slot 254 down slide surface 236 to the bead, where it forms a second coated layer on the first layer. The third coating liquid 256 passes through the third slot 258 down the slide surface 244 and over the second coating liquid 124 on the slide surface 236 to the bead, where it forms a third layer on the second layer.

A slide coating die of this invention using a steeper face angle than is possible with known systems is shown in Figure 22. The die 310 is positioned with the coating bead edge along the radius line R at an angle A_3, ranging from 35° to 90° and preferably 45° above horizontal. The slide surface 312 is at an angle A_6, ranging from 30° to 75° and

preferably 55° from the plane P tangent to the backup roller 314. This places the slide surface 312 at an angle A_7, 10° from vertical. Coating liquid is pumped through inlet channel 316 into a manifold 318 and through a coating slot 320 and down slide surface 312 to be coated onto the web 48. Bead stability is provided by a vacuum chamber 324, where the vacuum bar 326 is mounted and adjusted separately from the upstream bar support 328. Various slide surface lengths L can be chosen, depending on the coating liquid rheology and flow rate, to obtain a smooth, defect-free coating. The slide surface length L can range from 1.6 mm to 50.8 mm. Liquids with viscosities below 10 centipoise run better on slide lengths of 12.7 mm and less. Liquids with viscosities above 10 centipoise run better on slide lengths more than 12.7 mm.

In one example, the slide surface length was 38.1 mm, the overbite was 0.076 mm, and the convergence was 0.38°. Coating liquid having a viscosity of 100 centipoise was coated on aluminum foil at a web speed of 15.2 m/min. The vacuum was 63.5 mm H_2O, the coating gap was 0.508 mm, and the wet layer thickness was 0.027 mm (G/Tw = 18.8). The coating was smooth and defect free.

Figure 23 shows a multiple layer version of the die of Figure 22. Figure 24 shows a multiple layer, combination extrusion and slide version of the die of Figure 22. Overbite and convergence are as shown above. In both cases, the preferred edge angle A_1 is 80°.

CLAIMS

1. A multiple layer die coating apparatus for coating multiple layers of fluid coating onto a surface comprising:

a die 100 having an upstream bar 104 with an upstream lip, a wedge bar 106 with a wedge edge, and a downstream bar 108 with a downstream lip, wherein the upstream lip is formed as a land 140, the wedge edge is formed as a sharp edge 136, and the downstream lip is formed as a sharp edge 134; and

a first passageway 118 running through the die between the upstream bar 104 and the wedge bar 106 and a second passageway 126 running through the die 100 between the wedge bar 106 and the downstream bar 108, wherein the first passageway comprises a first slot 122 defined by the upstream lip and the wedge edge and the second passageway comprises a second slot 130 defined by the wedge edge and the downstream lip; and

wherein a first coating fluid 116 exits the die from the first slot 122 to form a continuous coating bead between the upstream die lip, the wedge edge, and the surface being coated for application onto the surface being coated, wherein a second coating fluid 124 exits the die from the second slot 130 to form a continuous coating bead between the wedge edge, the downstream die lip, and the surface being coated for application onto the first coating fluid.

2. A multiple layer die coating apparatus for coating multiple layers of coating fluid onto a surface comprising:

a die 150 having an upstream bar 154 with an upstream lip, a separator 156, and a downstream bar

158 with a downstream lip, wherein the upstream lip is formed as a land 182 and the downstream lip is formed as a sharp edge 178; and

a first passageway 166 running through the die between the upstream bar 154 and the separator 156 and a second passageway 170 running through the die between the separator 156 and the downstream bar 158, wherein the first and second passageways combine to form a single slot 174 defined by the upstream lip and the downstream lip; and

wherein the two coating fluids 116, 124 are brought together inside the die slot 174 and flow through the slot as separate, laminar layers which form a coating bead and transfer to the surface to be coated.

3. The die of claim 2 wherein the separator 156 comprises one of a slot shim or a wedge.

4. The die of any of claims 1-3 further comprising means for improving coating performance by changing at least one of the slot heights H, the overbites O, and the convergence C, wherein the slot heights, the overbites, and the convergence are selected in combination with each other and wherein the length L of the land, the edge angle A_1 of the downstream bar, the die attack angle A_2 between the downstream bar surface of the coating slot and a tangent plane through a line on the surface to be coated parallel to, and directly opposite, the sharp edge, and the coating gap distance G between the sharp edge and the surface to be coated are selected in combination with each other.

5. The die of any of claims 1 and 2 further comprising a slide surface 236, 244 along

which at least one of the layers of coating fluid slides.

6. A die coating apparatus for coating fluid coating onto a surface comprising:

a die 220 having an upstream bar 226 with an upstream lip, a manifold bar 228, a downstream bar 232 with a downstream lip, a vacuum bar 224, and a slide surface 236, wherein the upstream lip is formed as a land and the first manifold bar is formed as a sharp edge 238; and

a first passageway running through the die between the manifold bar and the downstream bar, wherein coating fluid exits the die from the passageway and slides along the slide surface 236 to form a continuous coating bead between the manifold bar sharp edge, the upstream die lip, and the surface being coated.

7. The die of any of claims 1, 2, and 6 wherein the shape of the land conforms to the shape of the surface being coated.

8. A method of die coating multiple layers of fluid coating onto a surface coating comprising:

passing a first coating fluid 116 through a first slot 122 defined by an upstream bar 104 with an upstream lip and a wedge bar 106 with a wedge edge, wherein the upstream lip is formed as a land 140 and the wedge edge is formed as a sharp edge 136;

passing a second coating fluid 124 through a second slot 130 defined by the wedge bar 106 and a downstream bar 108 with a downstream lip wherein the downstream lip is formed as a sharp edge 134;

forming a continuous coating bead with the first coating fluid 116 between the upstream die lip,

the wedge edge, and the surface being coated for application onto the surface being coated; and

forming a continuous coating bead with the second coating fluid 124 between the wedge edge, the downstream die lip, and the surface being coated for application onto the first coating fluid.

9. A method of die coating multiple layers of fluid coating onto a surface coating comprising:

passing a first coating fluid 116 through a first passageway 166 defined by an upstream bar 154 with an upstream lip and a separator 156, wherein the upstream lip is formed as a land 182;

passing a second coating fluid 124 through a second passageway 170 defined by the separator 156 and a downstream bar 158 with a downstream lip wherein the downstream lip is formed as a sharp edge 178, and wherein the first and second passageways combine to form a single slot 174 defined by the upstream lip and the downstream lip;

bringing together the first and second coating fluids 116, 124 inside the die slot;

flowing the first and second coating fluids 116, 134 through the slot 174 as separate, laminar layers which form a coating bead; and

transferring the bead to the surface to be coated.

10. The method of any of claims 8 and 9 further comprising the steps of:

selecting the length L of the land, the edge angle A_1 of the downstream bar, the die attack angle A_2 between the downstream bar surface of the coating slot and a tangent plane through a line on the surface to be coated parallel to, and directly opposite, the downstream lip sharp edge, and the coating gap

distance G between the sharp edge and the surface to be coated in combination with each other; and

selecting the slot height H, the overbite O, and the convergence C in combination with each other.

11. The method of claim 8 further comprising the step of sliding at least one of the first and second coating fluids 116, 124 along a slide surface 236, 244 after the coating fluid exits the slot.

12. A method of die coating comprising:

passing coating fluid 116 through a passageway defined by a manifold bar 228 having a sharp edge and a downstream bar 232 with a downstream lip; and

sliding the coating fluid 116 exiting from the passageway along a slide surface 236 to form a continuous coating bead between the manifold bar sharp edge, an upstream die lip formed as a land, and the surface being coated.

13. The method of claim 12 further comprising the steps of:

selecting the length L of the land, the edge angle A_1 of the manifold bar, and the coating gap distance G between the sharp edge and the surface to be coated in combination with each other; and

selecting the overbite O and the convergence C in combination with each other.

14. The method of any of claims 8, 9, and 13 further comprising the step of selecting the shape of the land to conform to the shape of the surface being coated.

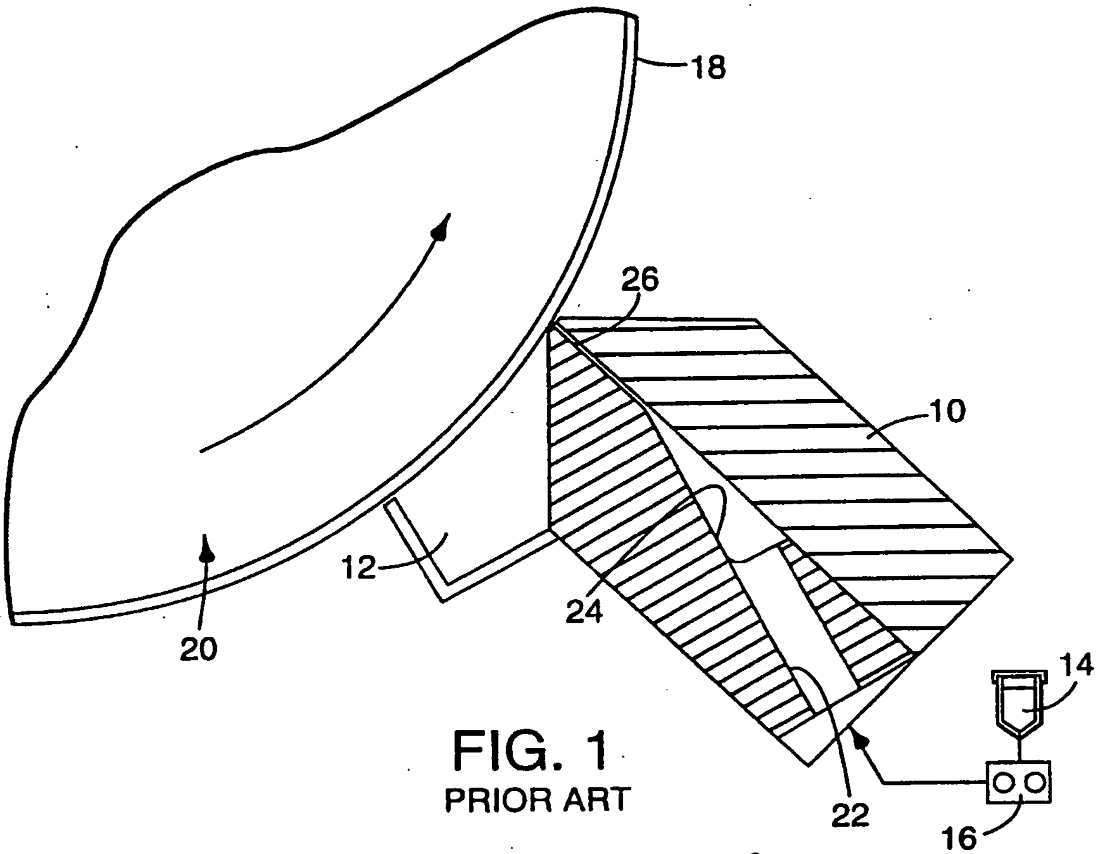

FIG. 1
PRIOR ART

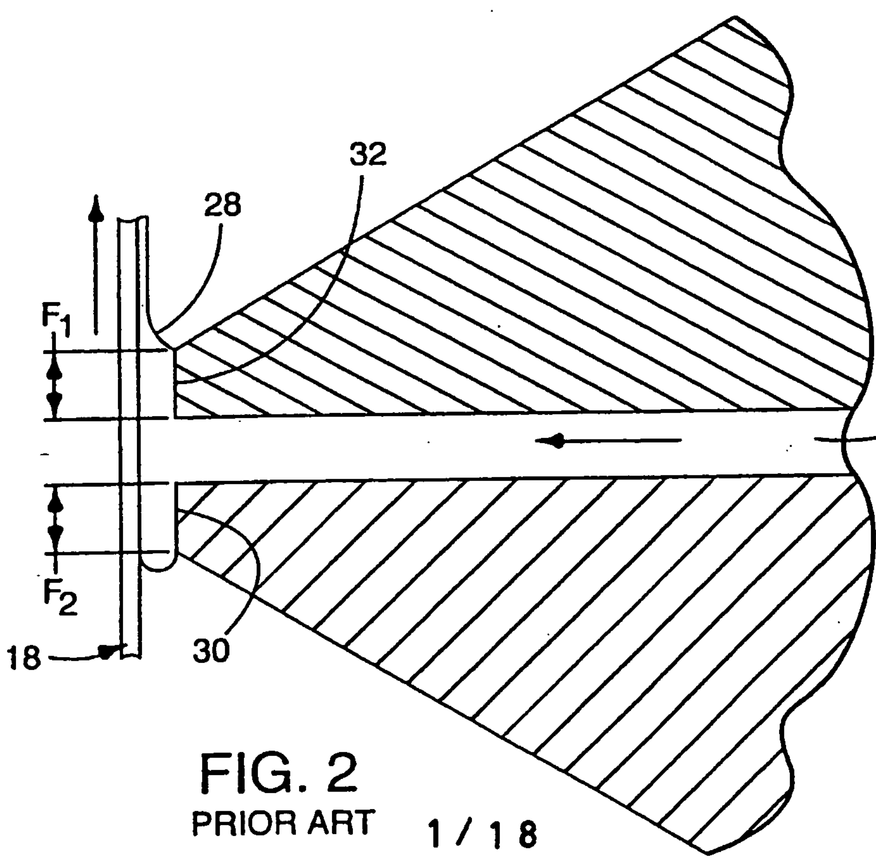

FIG. 2
PRIOR ART

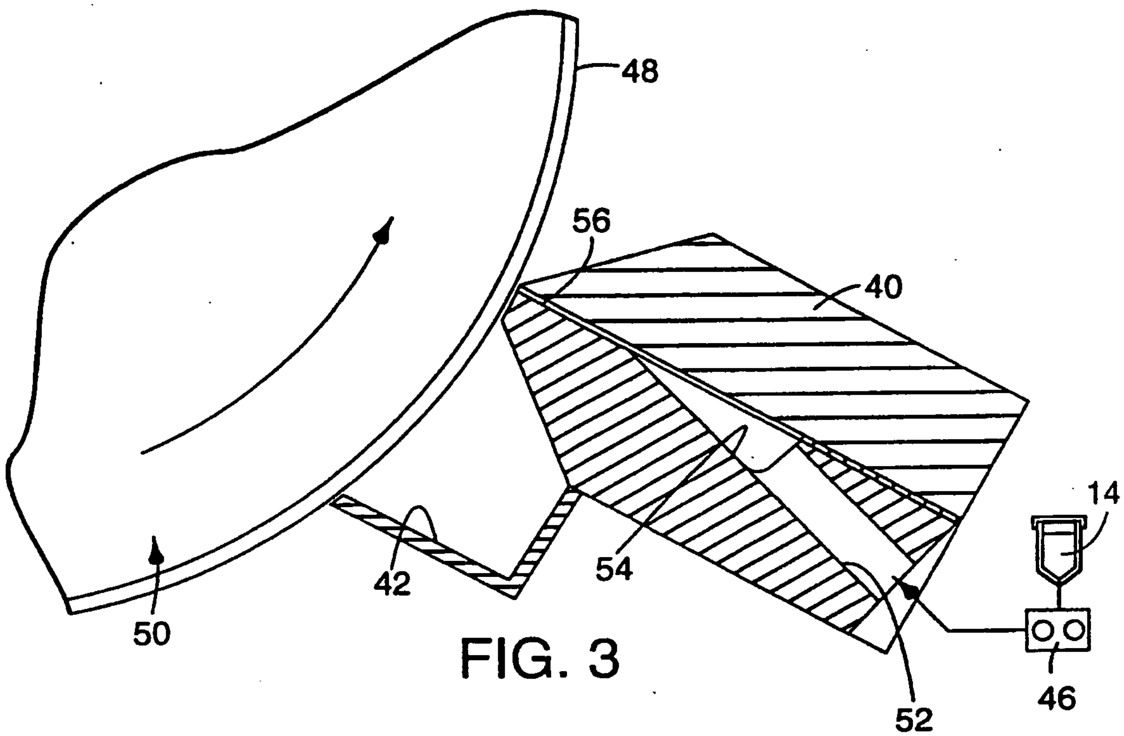

FIG. 3

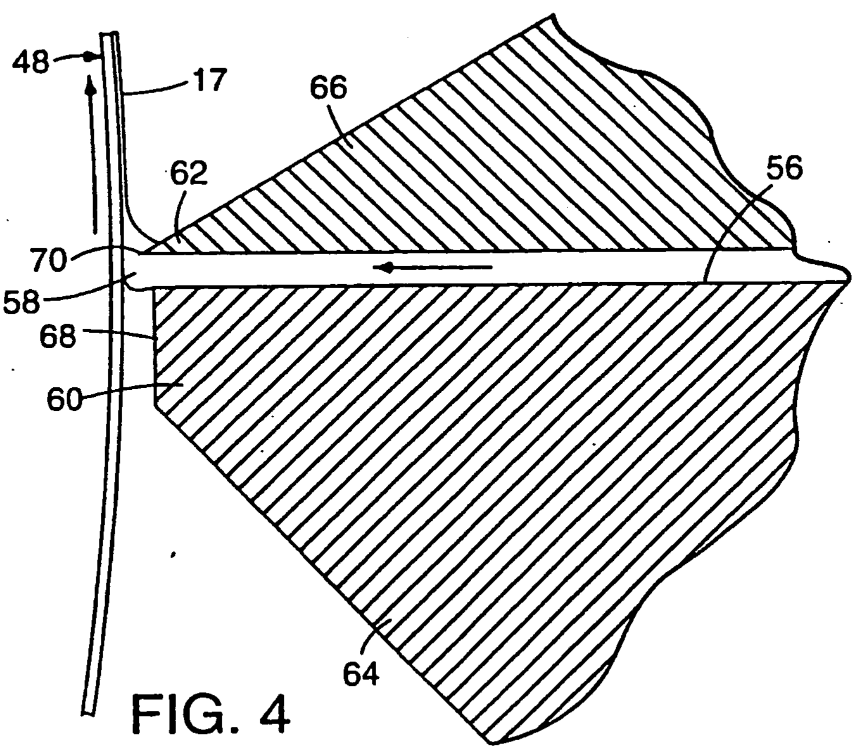

FIG. 4

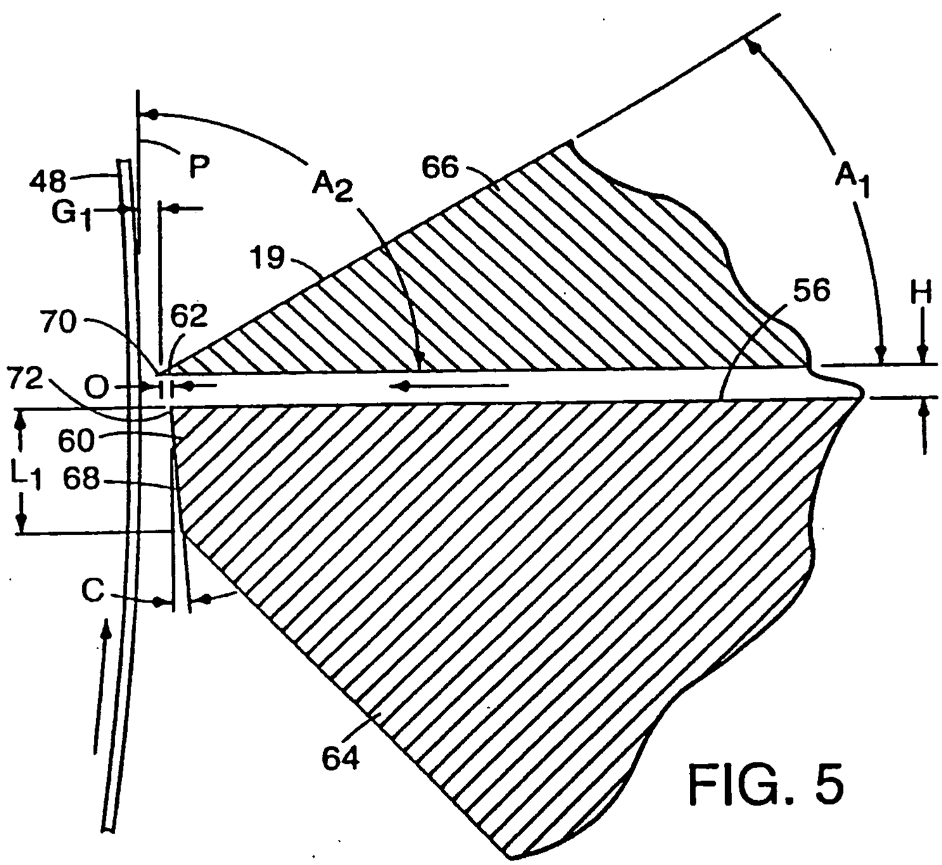

FIG. 5

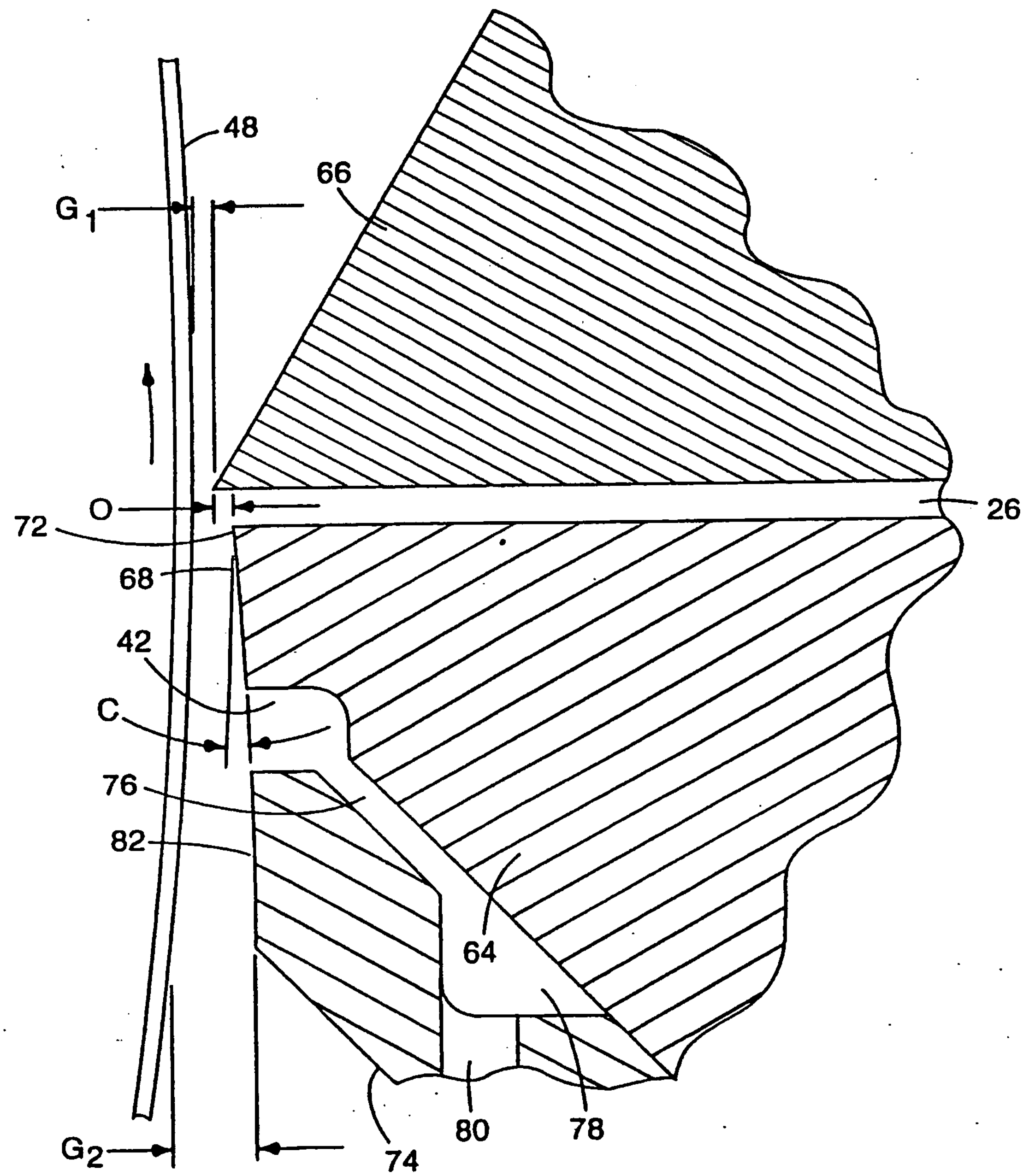

FIG. 6

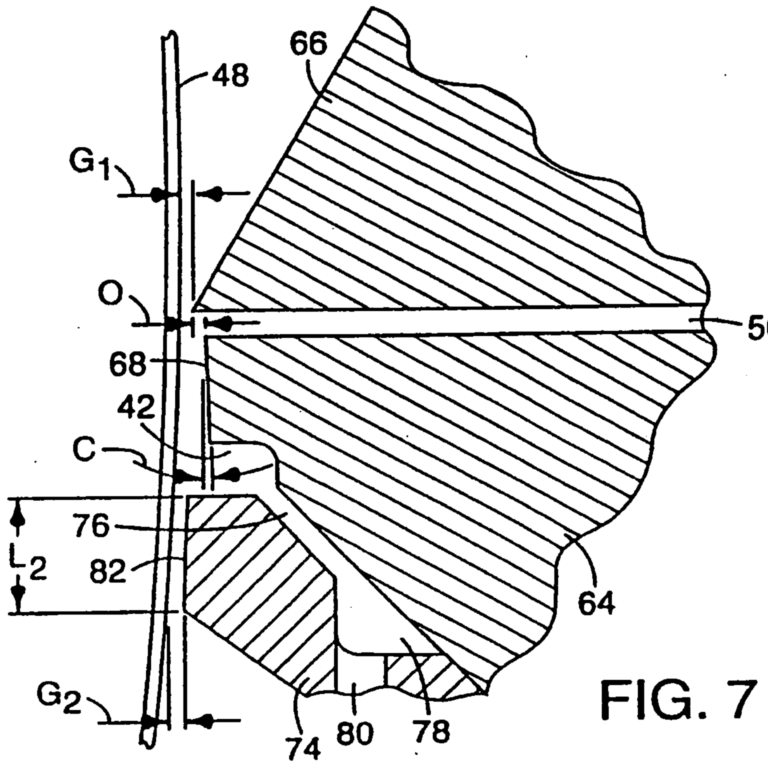
66
48
G_1
O
56
68
42
C
76
L_2
82
64
G_2
74
80
78

FIG. 7

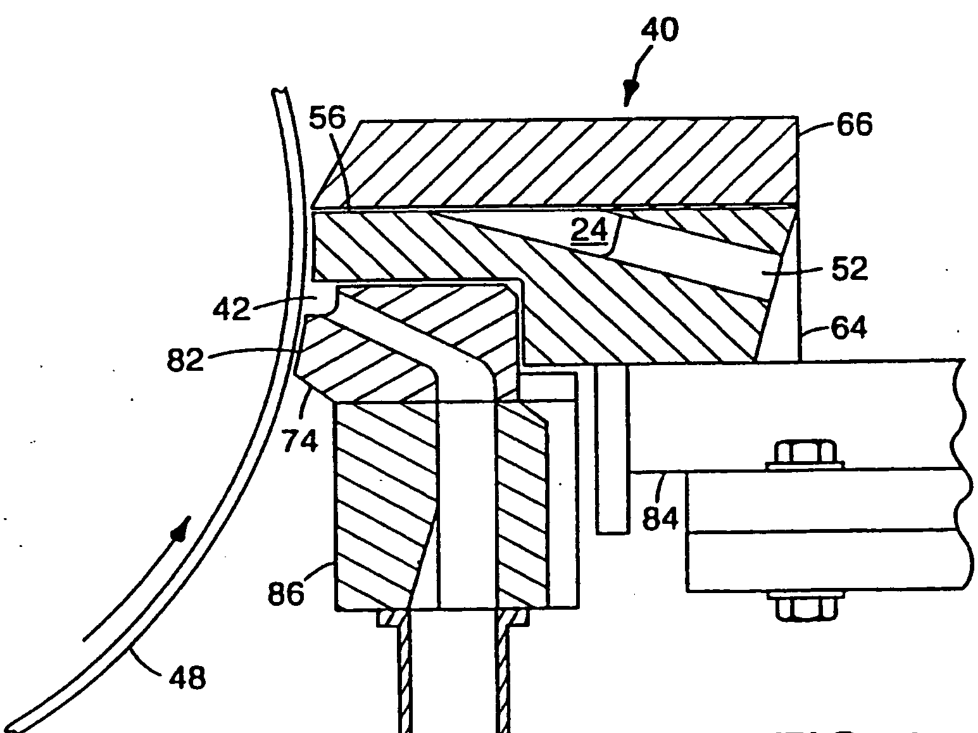
40
56
66
24
52
42
64
82
74
84
86
48

FIG. 8

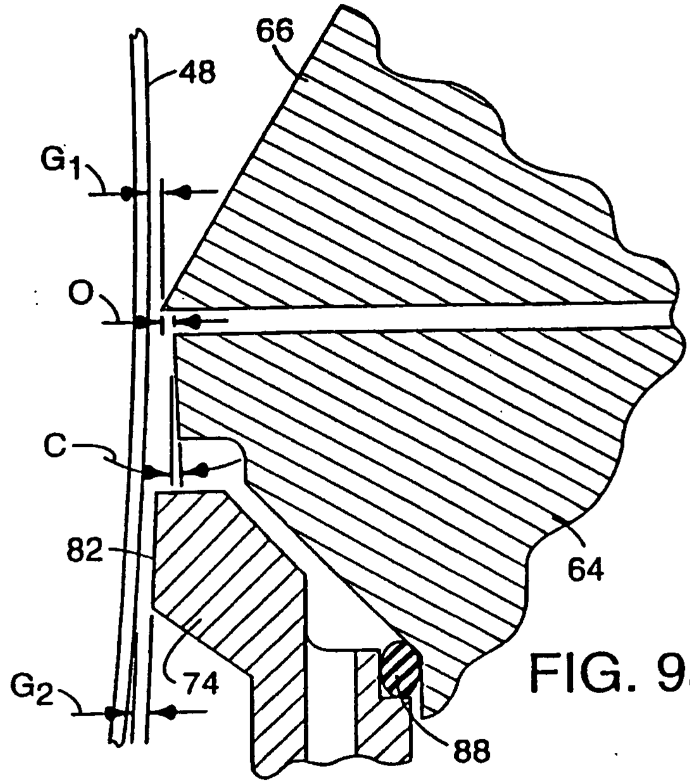

FIG. 9a

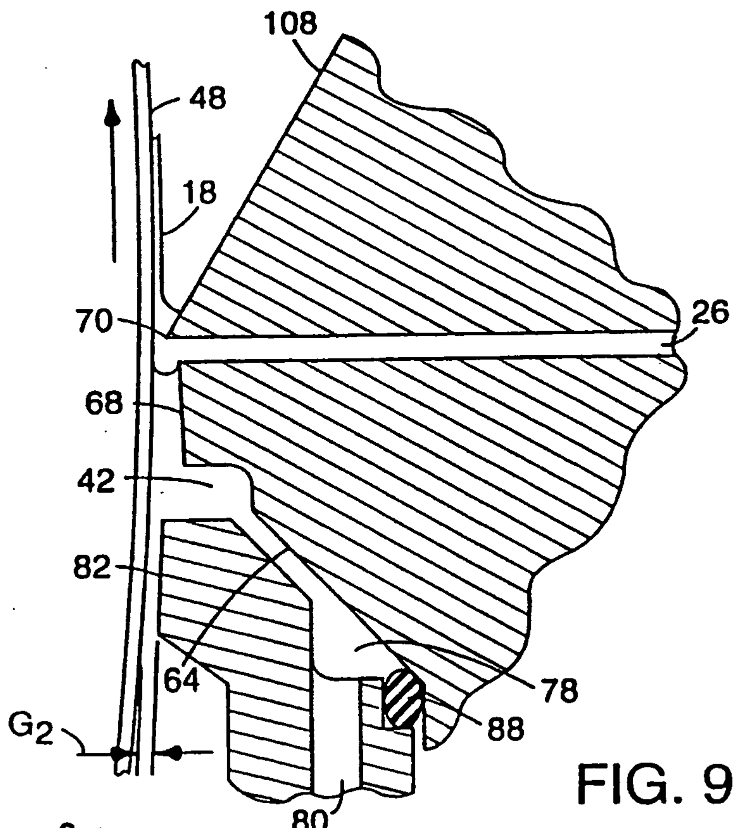

FIG. 9b

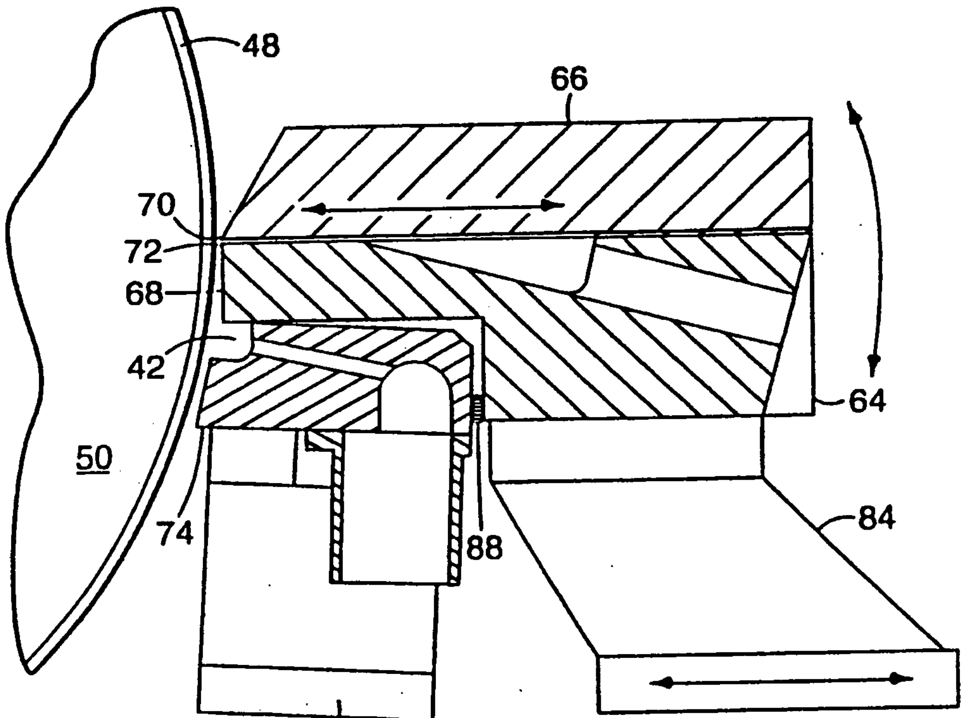

FIG. 10a

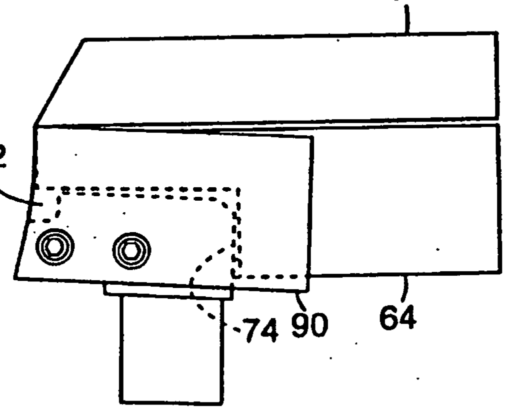

FIG. 10b

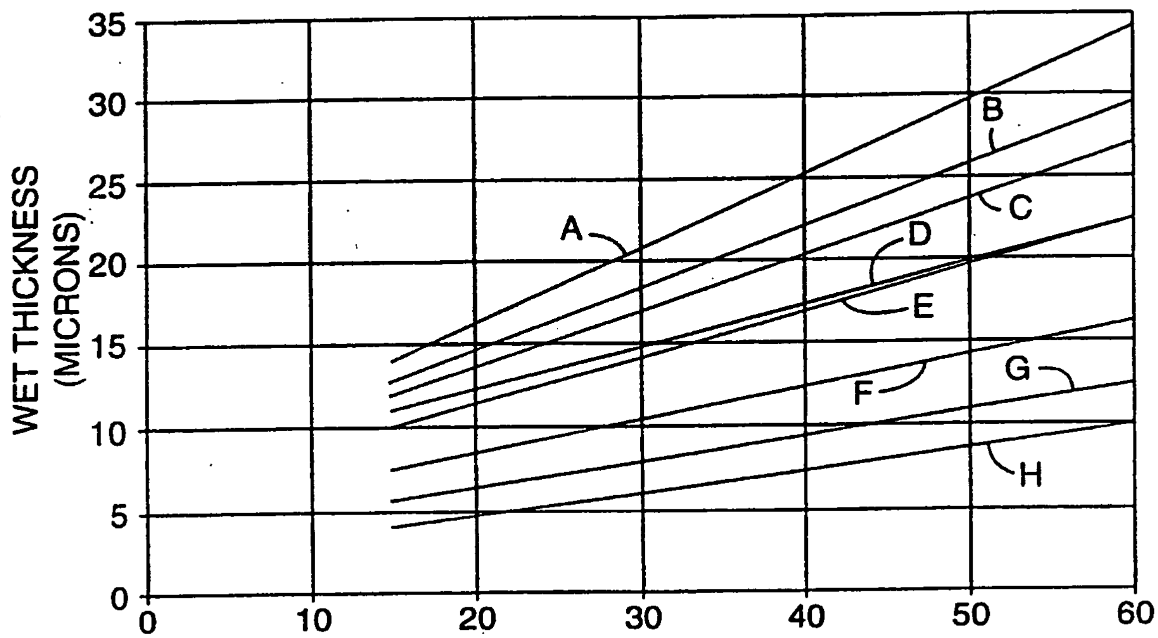
35
30
25
20
15
10
5
0
WET THICKNESS (MICRONS)
0
10
20
30
40
50
60
A
B
C
D
E
F
G
H
WEB SPEED (M/MIN)

FIG. 11

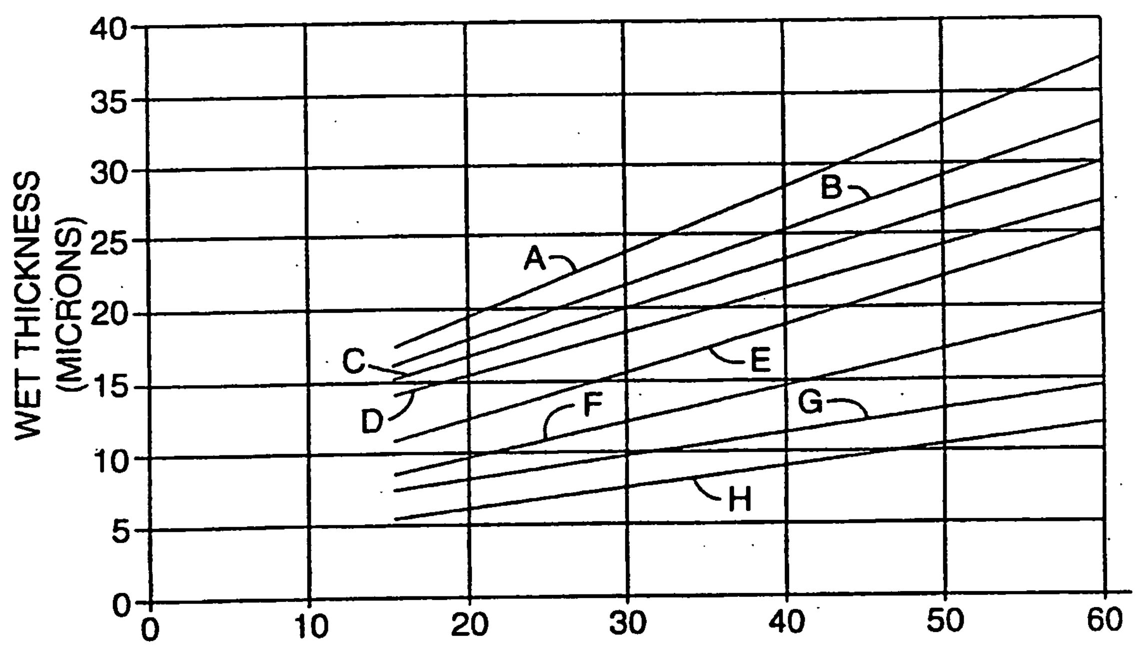
40
35
30
25
20
15
10
5
0
WET THICKNESS (MICRONS)
0
10
20
30
40
50
60
A
B
C
D
E
F
G
H
WEB SPEED (M/MIN)

FIG. 12

VIS (CPS)	Vw (M/MIN)		Tw (MICRONS)		CTG GAP (MM)		VAC (MM H20)	
	PRIOR	NEW	PRIOR	NEW	PRIOR	NEW	PRIOR	NEW
37.6	9.1		22.2		0.076		190.5	
37.6		18.3		15.4		0.076		96.5
37.6		24.4		15.4		0.076		101.6
39.5	18.3	18.3	42	31	0.076	0.124	132.1	43.2
39.5	36.6	36.6	47.2	31	0.076	0.099	165.1	93.9
47	30.5	30.5	45.7	45.7	0.102	0.254	109.2	5.1
131.4	18.3	18.3	62	62	0.102	0.264	66	0
131.4		38.1		62		0.305		0
140	12.2	12.2	33.8	23.1	0.076	0.081	101.6	104.1
158	9.1		46.5		0.076		76.2	
158		15.2		23.2		0.076		167.6
600	15.2	15.2	177.3	177.3	0.254	0.432	0	0
600	24.4	24.4	177.3	177.3	0.254	0.305	25.4	0

FIG. 13

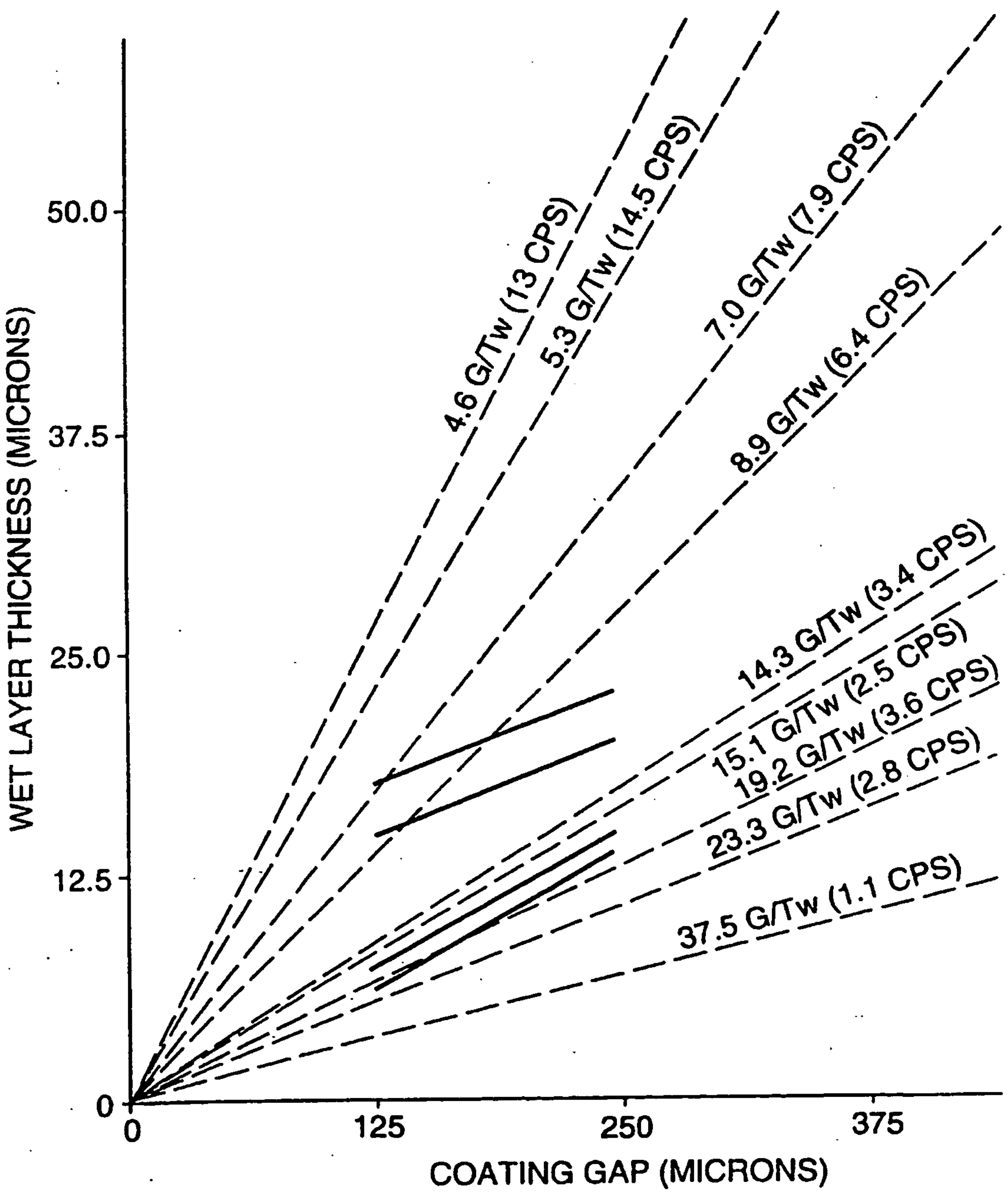
WET LAYER THICKNESS (MICRONS)
50.0
37.5
25.0
12.5
0
0
125
250
375
COATING GAP (MICRONS)
4.6 G/Tw (13 CPS)
5.3 G/Tw (14.5 CPS)
7.0 G/Tw (7.9 CPS)
8.9 G/Tw (6.4 CPS)
14.3 G/Tw (3.4 CPS)
15.1 G/Tw (2.5 CPS)
19.2 G/Tw (3.6 CPS)
23.3 G/Tw (2.8 CPS)
37.5 G/Tw (1.1 CPS)

FIG. 14

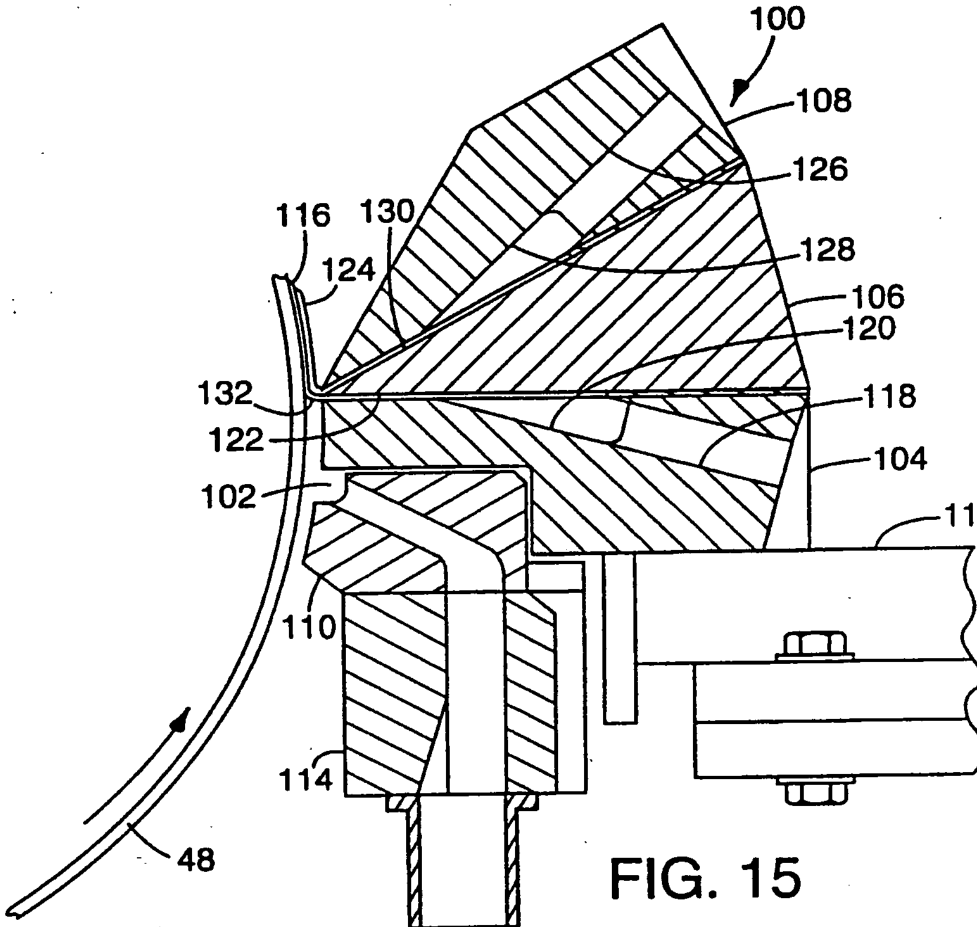
100
108
126
116
130
124
128
106
120
132
118
122
104
102
112
110
114
48

FIG. 15

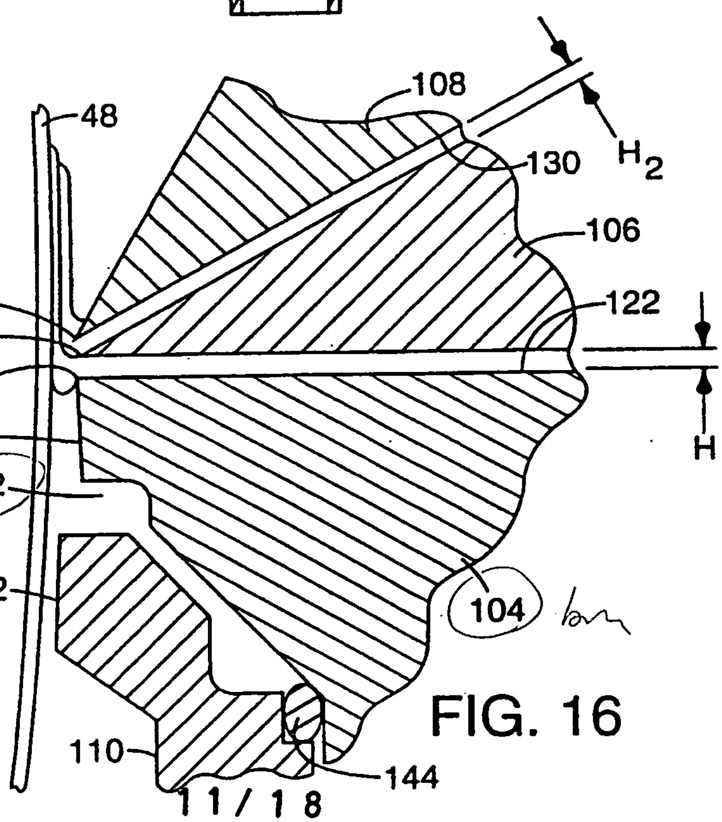
48
108
130
H2
106
134
122
136
138
140
H1
102
Vacuum chamber
142
104
bar
110
144

FIG. 16

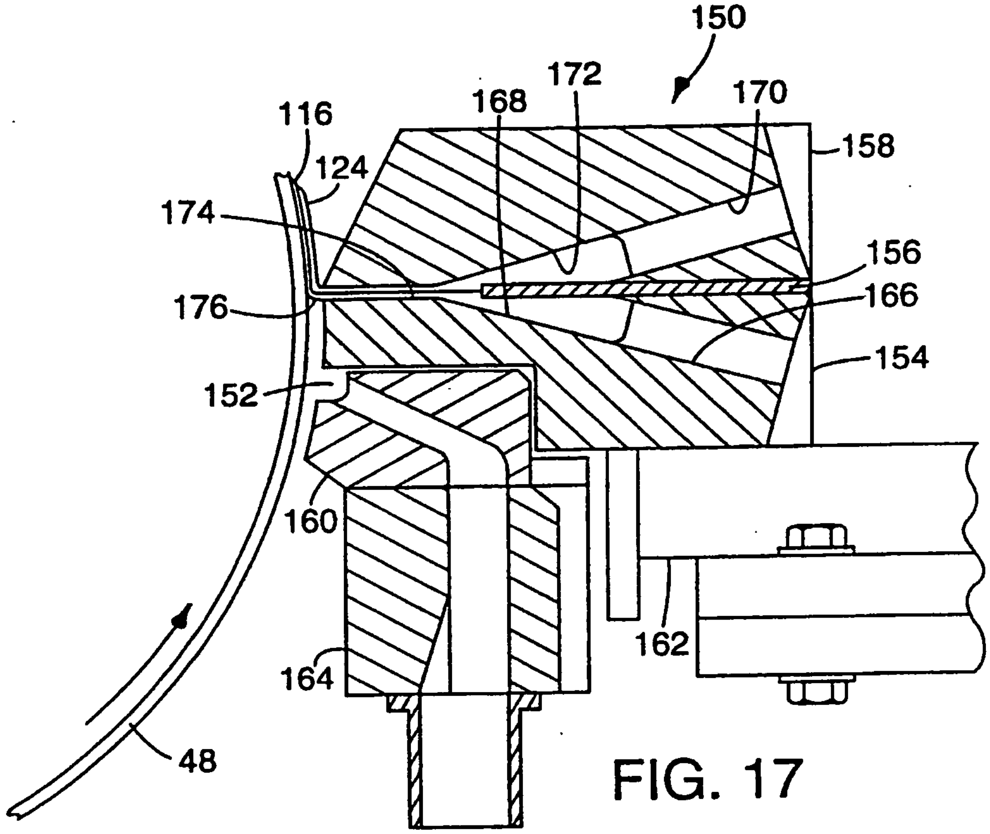
150
172
168
170
116
158
124
174
156
166
176
154
152
160
162
164
48

FIG. 17

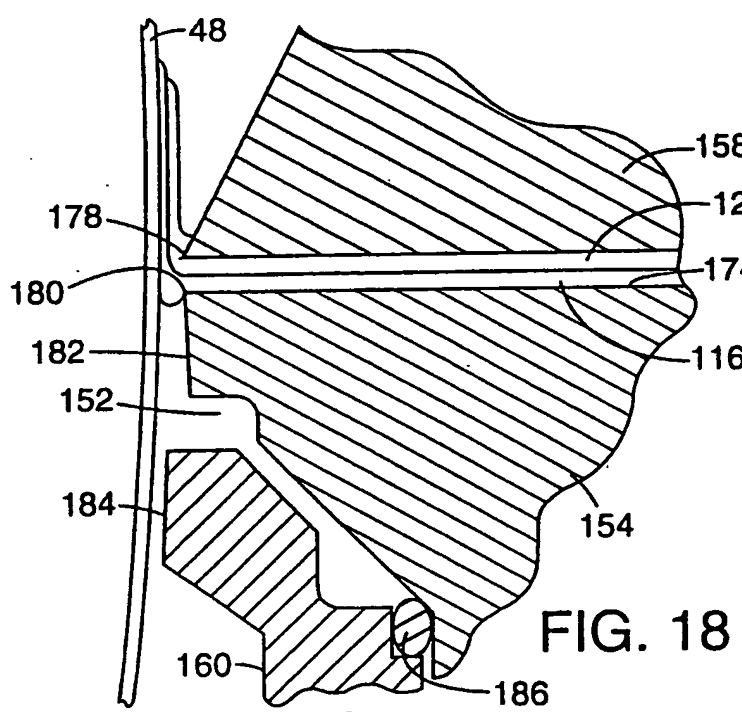
48
158
124
178
174
180
116
182
152
184
154
160
186

FIG. 18

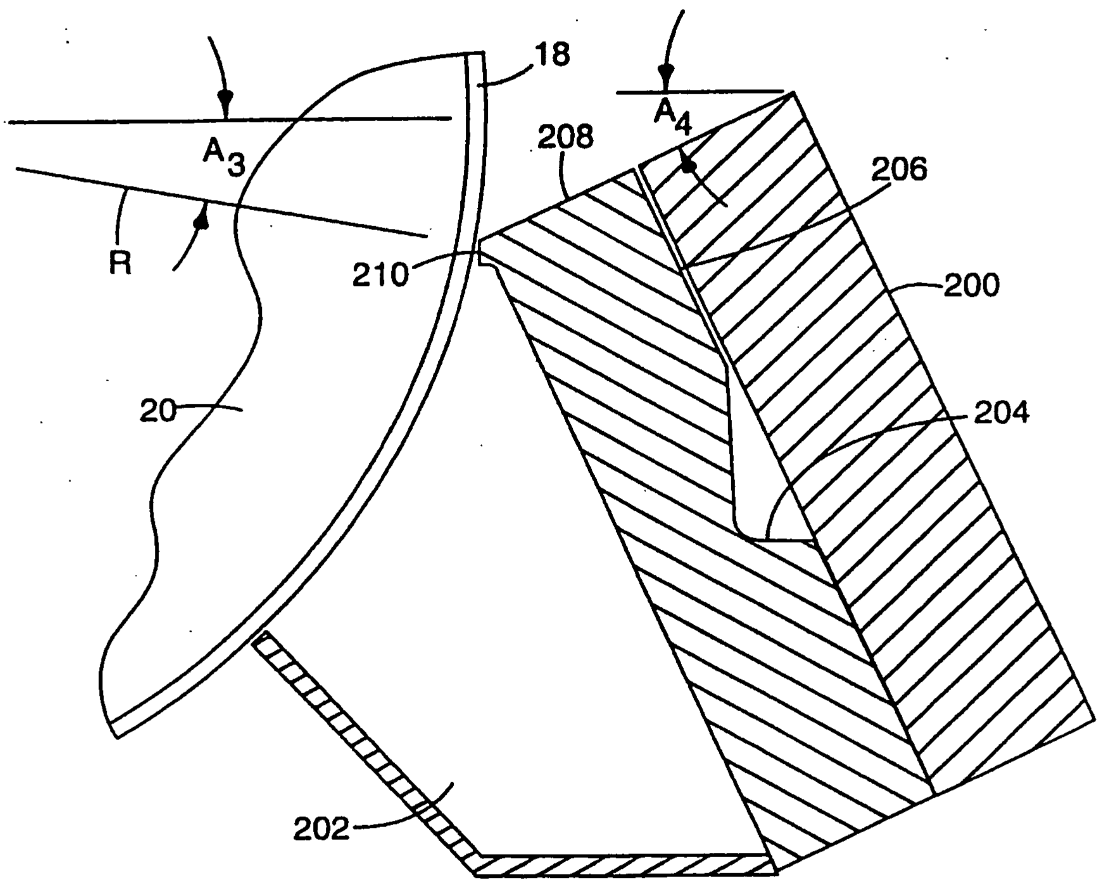

FIG. 19
PRIOR ART

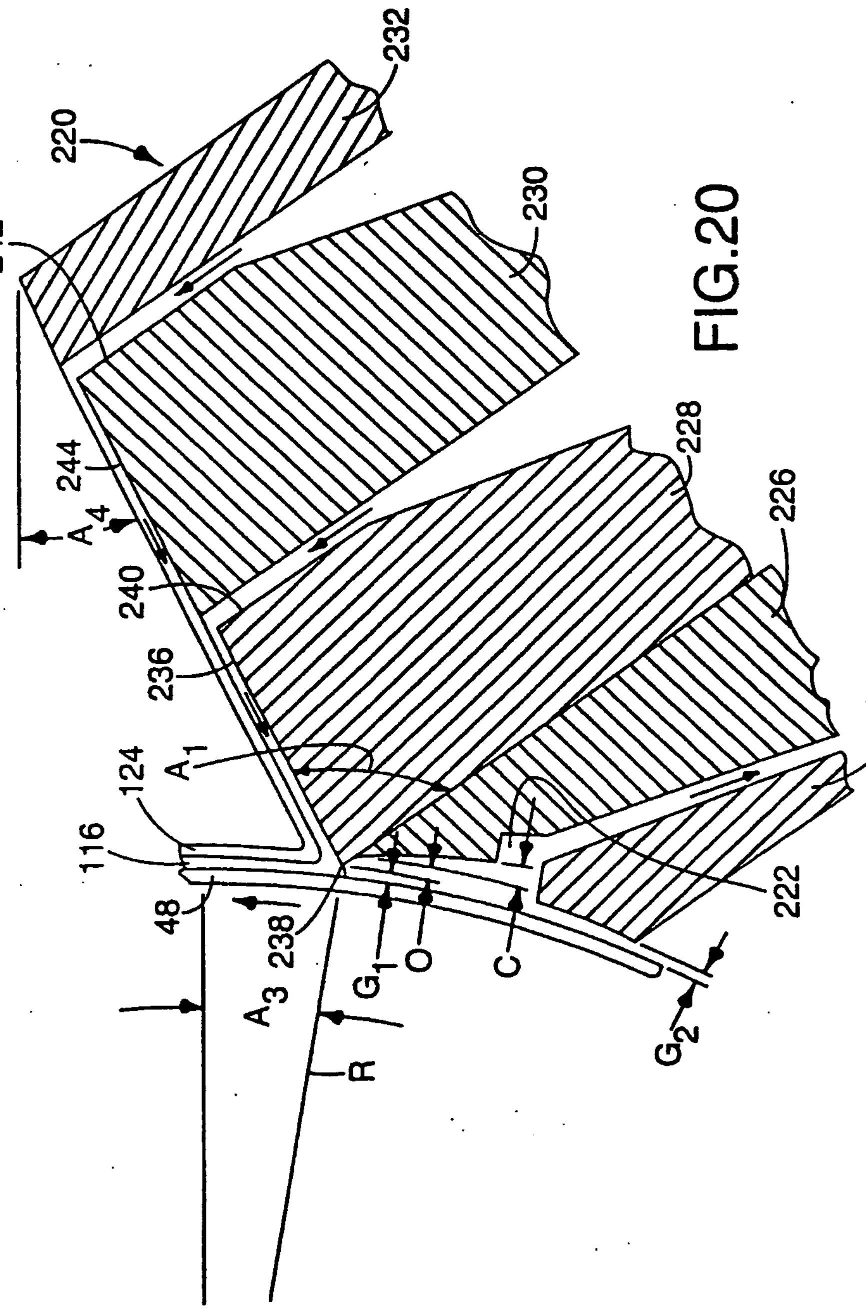
220
232
230
242
228
226
244
A_4
240
236
A_1
224
124
116
222
48
238
G_1
O
C
A_3
R
G_2

FIG.20

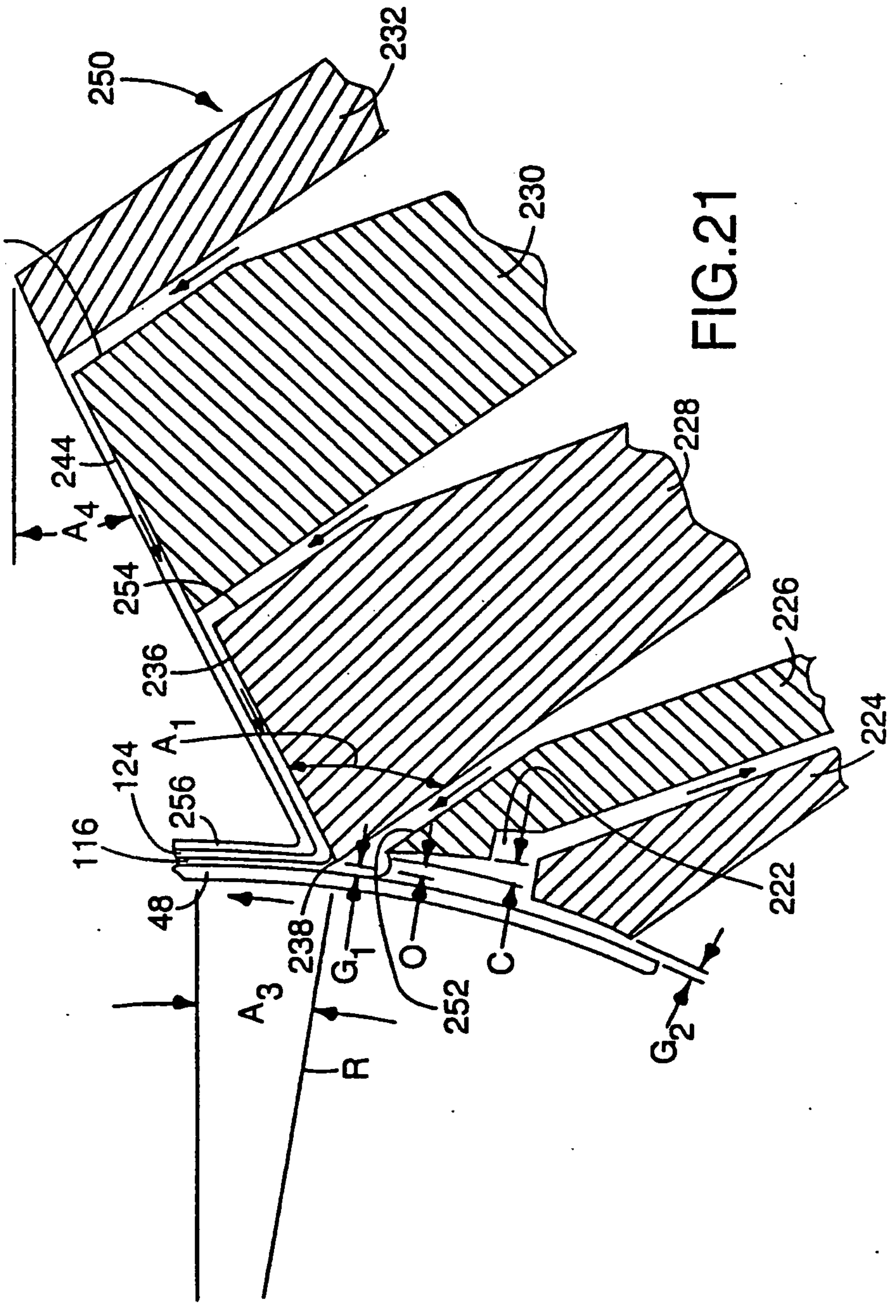
250
232
230
258
228
244
A_4
254
236
226
A_1
224
124
256
116
222
48
238
G_1
O
C
252
A_3
R
G_2

FIG.21

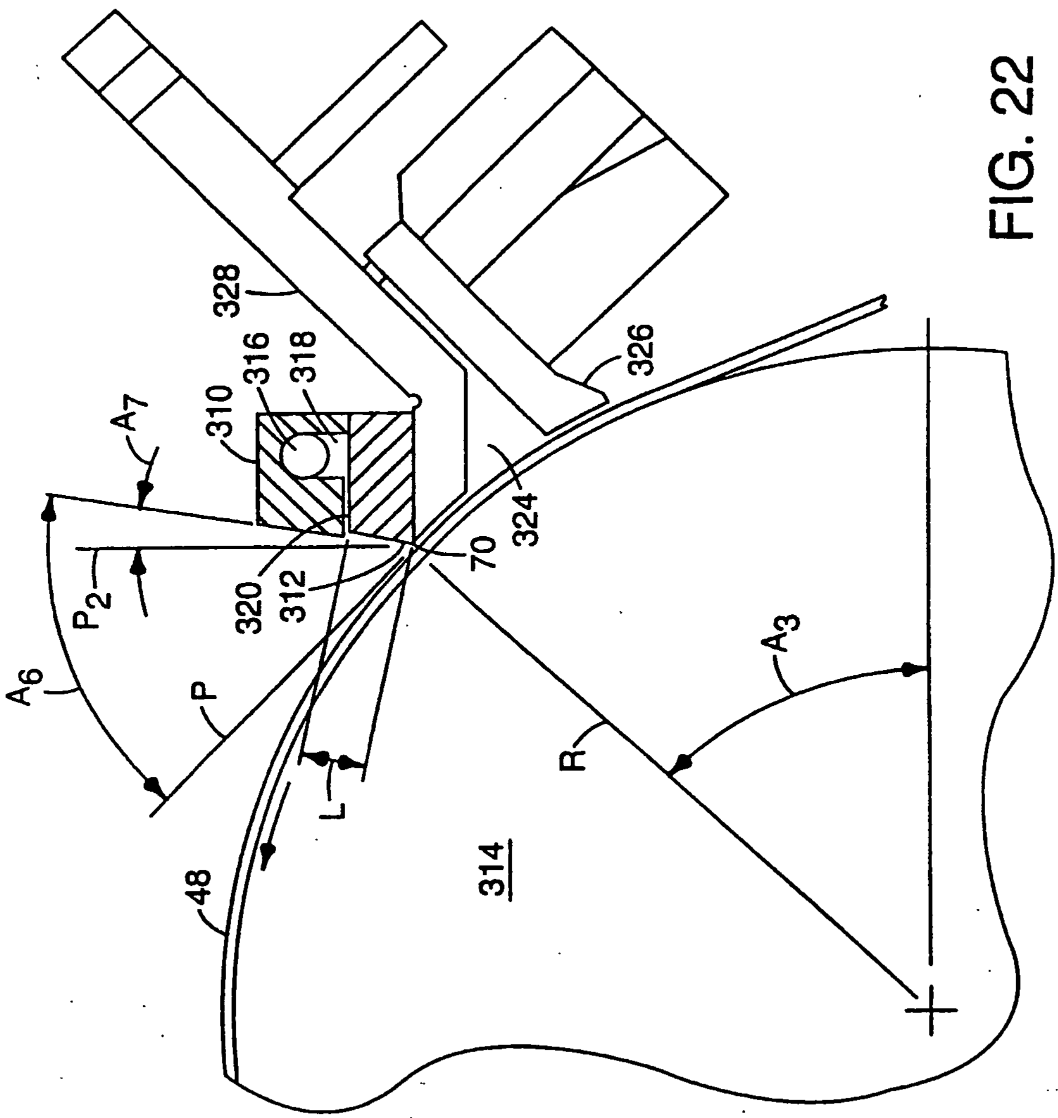

FIG. 22

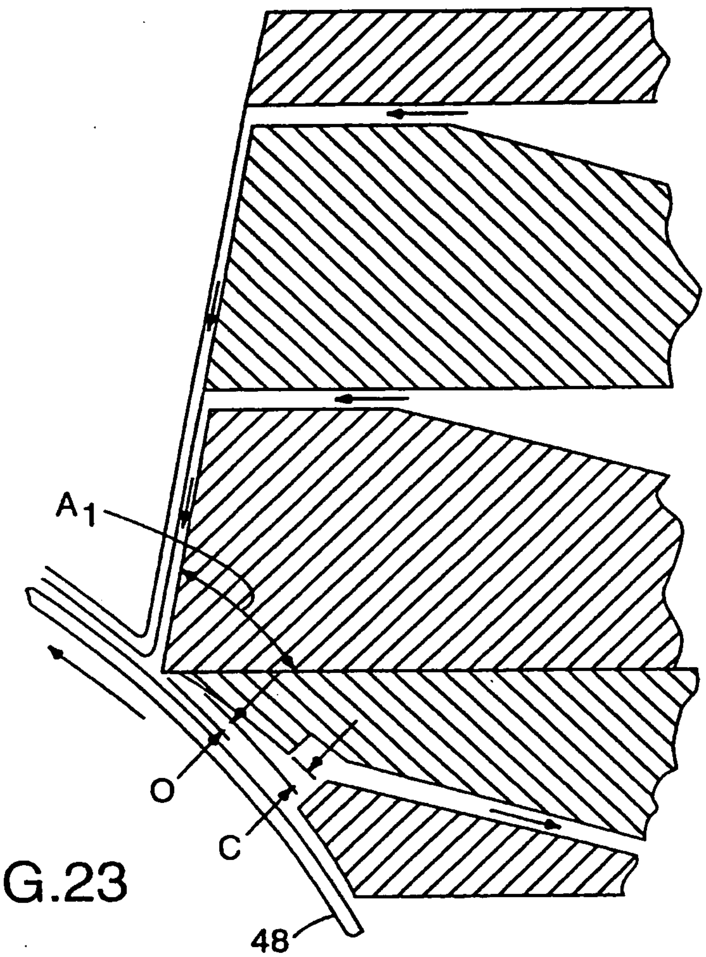

FIG.23

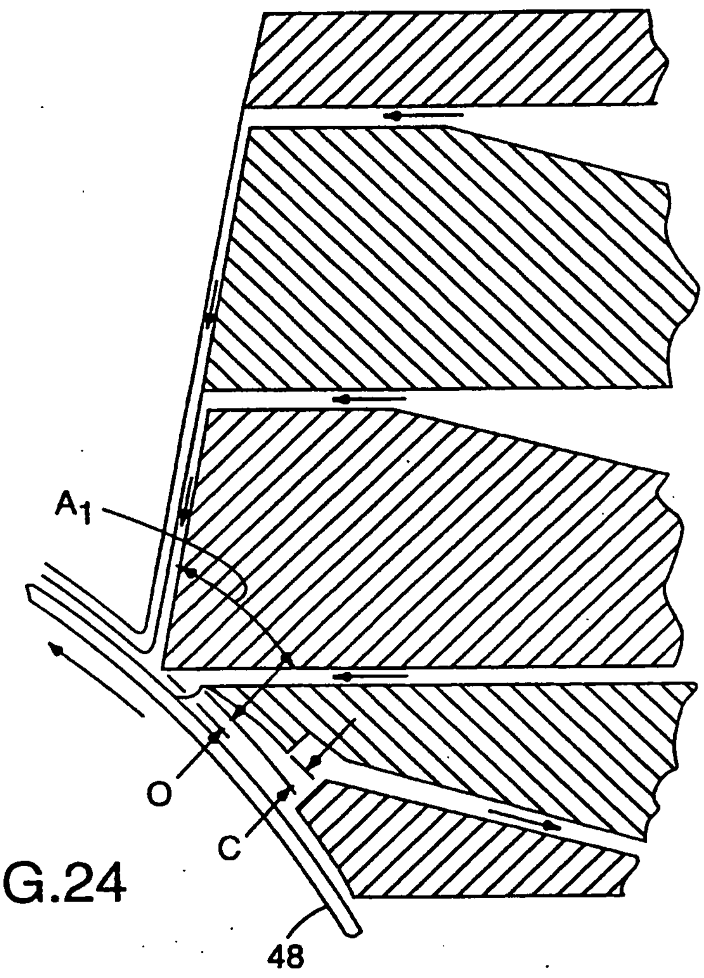

FIG.24

INTERNATIONAL SEARCH REPORT

Inte   onal Application No
PCT/US 95/03177

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   B05C5/02   B05C9/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   B05C G03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US-A-5 030 484 (CHINO ET AL) 9 July 1991	1,7,8, 10,14
A	see column 3, line 39 - column 4, line 3; figures 1,2,4	4

X	US-A-2 761 791 (T.A. RUSSEL) 4 September 1956 cited in the application	1,5, 10-12,14
A	see column 13, line 40 - line 64; figures 2,3,9-11	2

A	US-A-4 774 109 (HADZIMIHALIS) 27 September 1988 see column 7, paragraph 3; figure 3	1,4

A	EP-A-0 566 124 (FUJI) 20 October 1993 see page 4, line 1 - page 5, column 17	1

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 September 1995	09.10.95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Guastavino, L

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 95/03177

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,4 443 504 (BURKET ET AL.) 17 April 1984 see abstract; figure 1 see column 3, paragraph 2	6,12
A	WO,A,92 17816 (EASTMAN KODAK) 15 October 1992 see abstract; figure 1	6,12,13
A	EP,A,0 552 653 (DU PONT DE NEMOURS) 28 July 1993 see abstract; figures 1,2	6,12
A	US,A,4 283 443 (CHOINSKI) 11 August 1981 see the whole document	6,12
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A	US,A,4 842 900 (MIYAMOTO) 27 June 1989 see abstract; figures 4,6	6,12
X A	EP,A,0 111 338 (DU PONT DE NEMOURS) 20 June 1984 see abstract; figure 3	12 13
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Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

SEE ANNEX

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US95/03177

FURTHER INFORMATION CONTINUED FROM PCT/ISA/210

1.Claims 1,4,5,7,8,10,11,14: die with an upstream land,a wedgw and a sharp downstrem edga,and associated method

2.Claims 2,3,9: die with a single slot between the upstream and the downstream lip,and associated method

3.Claims 6:die with a vacuum bar

4.Claims12,13: method of die coating with a sliding surface